GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION

SPONSORED PROJECT INITIATION

Date: 8/22/79

Project Title: Data Communication Link for Remote Interactive Graphics

Project No: A-2433

Project Director: Mr. L. P. Elam

Sponsor: General Electric Company; Appliance Park, Louisville, KY 40225

Agreement Period: From 8/3/79 Until 9/30/79

Type Agreement: Purchase Order No. 118-G226-900144-V17 dated 8/3/79

Amount: $16,404

Reports Required: Interim Report (Phase I)

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Defense Priority Rating: none

Assigned to: CSTL/CAD (School/Laboratory)

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CA-3 (3/76)

GEORGIA INSTITUTE OF TECHNOLOGY
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SPONSORED PROJECT TERMINATION

Date: 7-31-80

Project Title: Data Communication Link for Remote Interactive Graphics

Project No: A-2433

Project Director: Mr. L. P. Elam

Sponsor: General Electric Company; Appliance Park, Louisville, KY 40225

Effective Termination Date: 9/30/79

Clearance of Accounting Charges: 9/30/79

Grant/Contract Closeout Actions Remaining:

- x Final Invoice ~~and Closing Documents~~
- _ Final Fiscal Report
- _ Final Report of Inventions
- _ Govt. Property Inventory & Related Certificate
- _ Classified Material Certificate
- _ Other ______________________

Assigned to: CSTL/CAD (~~School~~/Laboratory)

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✓ Reports Coordinator (OCA)
Library, Technical Reports Section
EES Information Office
Project File (OCA)
Project Code (GTRI)
Other ______________________

CA-4 (1/79)

A-2433

FINAL REPORT

Data Communications Link

for

Remote Interactive Graphics

EES/GIT Project A2433

Prepared

for

General Electric Company
Appliance Park AP 35-1123
Louisville, Ky 40225

Technical contact: G. D. Palmer

General Electric Company
Lighting Business Group
Nela Park
Cleveland, Ohio 44112

Technical contact: Calvin D. Kennedy

10 January 1980

Presented by

Computer Science and Technology Laboratory
Computer Technology Branch
Engineering Experiment Station
Georgia Institute of Technology
Atlanta, Georgia 30332

EXECUTIVE SUMMARY

This study has examined the suitability of four forms of communications for high speed data transfers at the General Electric Louisville Facility: coaxial line, microwave, laser, and fiber-optics. Designs for each of these approaches are presented in the report, and the major attributes of these systems are presented below.

Coaxial line transmission is a mature technology which can provide the desired service at a relatively low cost. Analog transmission is employed, resulting in a high degree of flexibility in the suitable signaling waveforms. In other words, the system is not highly tailored to the specific waveform required for the current graphics system. Also, the full channel capacity of each modulator-demodulator pair has not been fully utilized, thus providing some growth capacity. One of the more serious questions about this approach concerns reliability; thus, one design has been provided which should provide high reliability by eliminating active electronics in the exterior cable.

The second approach considered was that of microwave radio. Due to the transmission speed required by the General Electric network, it would be necessary to utilize a relatively high frequency microwave channel. Under normal circumstances, this factor would aid in satisfying requirements for a license for such an operation. However, the short path length would reduce the likelhood that a license would be granted. Traditionally, microwave links have been used for moderate-to-long paths. The microwave link should yield satisfactory performance, but, should it become necessary or desirable to alter the link characteristics, FCC approval will probably be needed to make the required changes. Furthermore, operation of the microwave system must be by FCC licensed operators.

The third approach considered was that of a through-the-atmosphere-laser link. The advantage of this approach is that it provides a communications channel of extremely high capacity. The major disadvantage is that the performance of such a link is highly sensitive to weather conditions, particularly rain and fog.

The fourth and possibly most attractive approach involves the use of a fiber-optics link. Two of the more attractive characteristics of a fiber-optics link are a high degree of immunity to electrical noise and very high transmission capacity. A limitation of this approach is that link spans are currently limited to a maximum of one to three kilometers for transmission speeds being considered for this application. Another limitation is that currently, no frequency division multiplexing capability exists for fiber-optics systems, and therefore all multiplexing is time division.

COST ESTIMATE FOR MICROWAVE EQUIPMENT AT LOUISVILLE

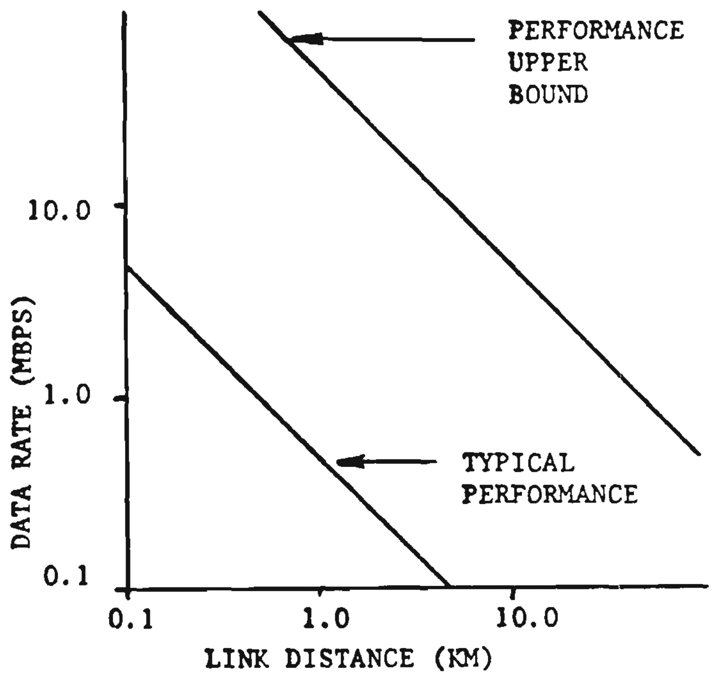
ITEM	NUMBER	COST EACH	TOTAL COST
Microwave Transmitter/Receiver	2	$11,100	$22,200
Duplexer	2	900	1,800
Antenna	2	600	1,200
Multiplex/demultiplex equipment	2	12,000	24,000
		TOTAL	$49,200

The optical paths indicated in figure 13 on page 27 have been chosen to limit the path length for any given link. Given clear weather, the path lengths are such that extremely low BERS(bit error rates) may be expected, and reasonable BERS, approximately one part in 10^{+6}, may be sustained even in moderate fog conditions.

Limitations are imposed on the coaxial line system with respect to maximum line length. For the modulated systems, such as those using CATV equipment, the limitations are from signal attenuation and its impact upon detection reliability. In other words, the maximum transmission distance is directly related to the required transmission reliability. The arrangement shown in figure 5 on page 16 is close to the maximum span which can be covered without active repeaters for two reasons: (1) It represents the maximum path length which will support high reliability transmission from a signal-to-noise point of view given typical coaxial lines. (2) The maximum continuous length of coaxial cable available is 10,000 feet, and this is a special order item.

For those systems which use coaxial line for baseband signaling, such as between IR repeaters, the maximum cable length is determined by both signal attenuation and signal dispersion, and the latter presents the more serious problem. In an ideal medium, all frequency components of a signal propagate at the same speed, and therefore time dispersion is no problem. However, the dielectric material used in modern coaxial lines is a good but not perfect transmission medium, and can cause a problem with time dispersion. Using good quality coaxial lines, it is possible to reliably transmit pulses whose duration is on the order of one microsecond over distances of several hundred feet.

The maximum link distance achievable with fiber optics systems depends upon transmitter power, receiver sensitivity, and cable loss. These characteristics vary with different product lines, but the upper performance bound for a typical combination is shown below.



RATE-DISTANCE CHARACTERISTICS FOR TYPICAL

INFRARED FIBER OPTICAL SYSTEMS

DATA COMMUNICATIONS LINK FOR REMOTE INTERACTIVE GRAPHICS

The manufacturing division of the Major Appliance Business Group of the General Electric Company of Louisville, Kentucky, has implemented an interactive graphics system to automate design, drafting, and documentation in support of Plant Engineering and Planning, and Manufacturing Technology and Equipment Development Operations of the Division of Advanced Manufacturing. The Lighting Business Group of the General Electric Company of Cleveland, Ohio, has implemented a similar system to automate design, drafting and documentation, providing essentially the same features as the Louisville system.

The present system consists of a central processing unit, four interactive graphics terminals at Louisville, Kentucky, and two interactive graphics terminals at Cleveland, Ohio.

Future expansion at the Kentucky site includes plans to locate a few interactive graphics terminal stations in remote locations up to 9,000 feet from the central processing unit. Future expansions at Cleveland call for satelliting terminal sites from the Nela Park central processing facility. The remote sites are just south of Twinsburg, approximately 18 miles from the Nela Park facility; Mentor, a little over 18 miles away; East 152nd Street, a little less than a mile away; and Richmond Heights, a little less than 2 miles away. The one major difference between the Louisville facility and the Cleveland installation is that in Louisville, GE owns the land between the remote site and the central processing facility, and in Cleveland, GE does not.

Installation of remote interactive graphics terminals at distances beyond 200 feet by conventional methods, using either ribbon cable or standard cable, can cause improper operation due to factors such as noise coupling and signal loss. Some of these problems can be eliminated by using balanced lines for common mode rejection techniques and by using <u>current</u> driver and receiver to provide greater distance drive capabilities. However, this method of laying cable and making connections is not recommended for data rates of 250,000 to 500,000 bits per second. These restrictions, potential reliability problems, and the disadvantage of direct connections necessitate a communications interface that is more sophisticated than the interconnection of terminals and wire. The fact that the information is transferred in the form of digital data between the central processing facility and the interactive graphics terminal necessitates a digital communications interface.

This report encompasses phases one and two of a five phase project. In phase one, EES collected technical data, reviewed written material, and examined schematics pertaining to the present interactive graphics system. Phase two, which was conducted in parallel with phase one, was a survey of existing systems potentially acceptable for the communications problem. The objective was to provide the appropriate technical approach for installation of a digital communications interface which will determine the interactive graphics protocol and electrical interfacing (timing and signal levels) with a serial data communications link.

The present system is comprised of a 19/G Design Console (interactive graphics terminal) and an IOS Controller (part of the central processing unit). These are subsystems of the interactive graphics computer system designed and manufactured by Computervision Corporation, Bedford, Massachusetts. EES, in surveying possible modes of communication for application at the Louisville and Cleveland facilities, found that the data rates required by the interface between the IOS Controller and the 19/G Design Console posed the greatest constraints on the communication paths.

The interface between the IOS Controller board and the 19/G Design Console required six parallel channels for communication: four channels for cursor control, and two channels for command communication and control.

The four channels for cursor control collectively provide X-position, X-sign, and Y-position, Y-sign information. The form of communications from the IOS Controller to the 19/G Design Console is a pulse stream which provides cursor movement. Each pulse represents a cursor movement of 4.6^{-3} inches for each pulse transmitted. The rate at which the pulses are transmitted is 250,000 bits per second per channel. The total band width for the four cursor control channels requires a communication bandwidth of one megahertz.

The two remaining channels are utilized for commands to the 19/G Design Console to control its operation, and for communication with the IOS Controller. The rate of communication required by the command channel between the IOS Controller and the 19/G Design Console and back to the IOS Controller is 500,000 bits per second. The command word is 20 bits of information, formatted with one start bit, 16 information bits, and three stop bits. The types of commands passed over the interface to the 19/G Design Console can be summarized into three groups: scope control, plotter control, and BIT pad control.

The figure below depicts the interface and the control channel interconnection with emphasis on identifying the signals intercommunication signals.

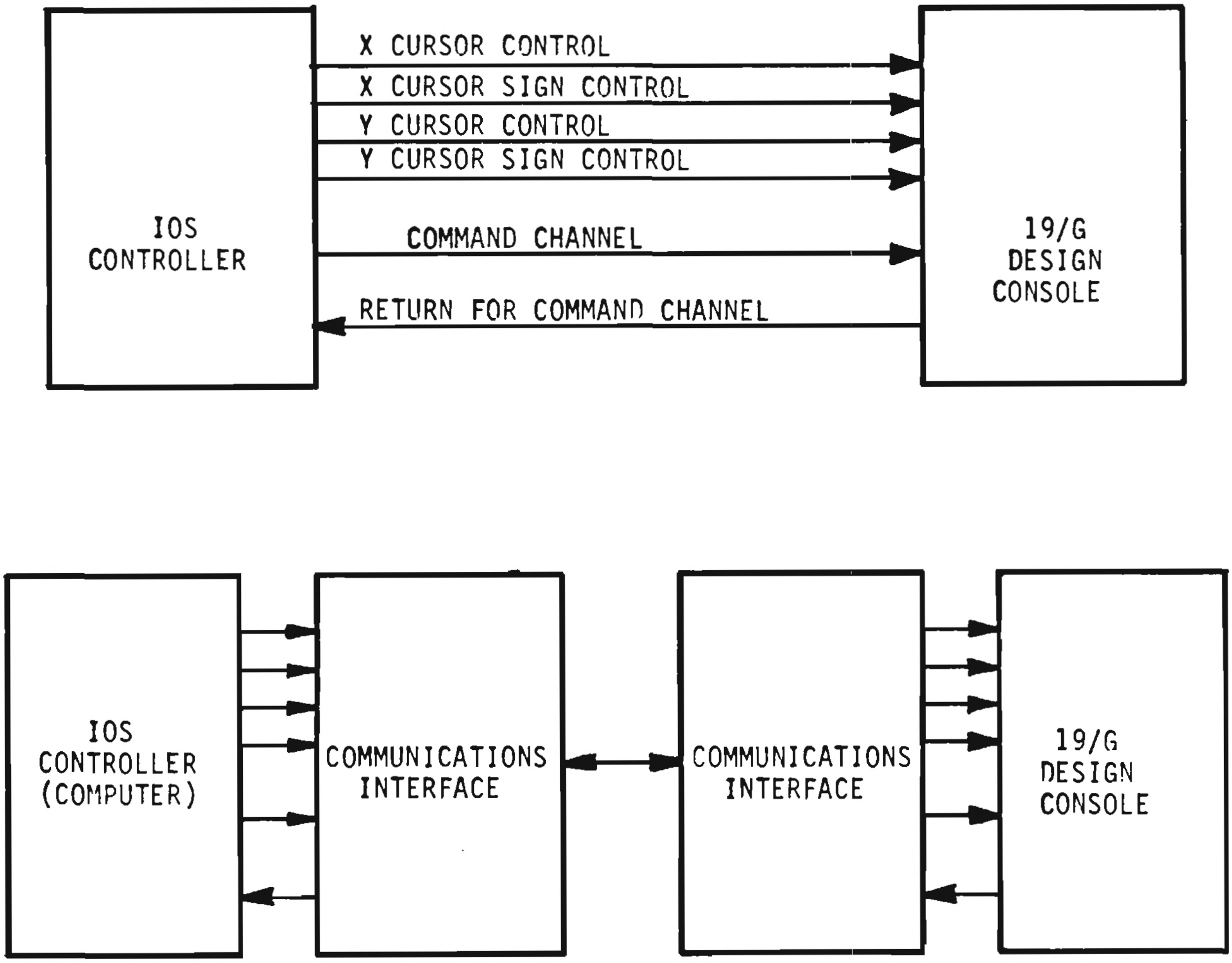


ILLUSTRATION OF INTERFACE BETWEEN THE IOS CONTROLLER AND THE 19/G DESIGN CONSOLE

FIGURE 2

The Louisville and Cleveland facilities present separate sets of problems. Louisville is basically a short haul, line of sight communication path. EES has some concern regarding licensing for a microwave system in applications requiring such a short distance. It is questionable whether the FCC would grant a license for such a system, particularly since other viable systems exist. Cleveland, on the other hand, requires two very long communication paths of approximately 18 statute miles each, to Mentor and to Twinsburg, and two short communications paths from Nela Park to the East 152nd Street facility and to the Richmond Heights facility.

There are several alternatives to the shorter communications path at the Louisville facility since the facility lends itself to communication between structures using optics, such as infrared laser. Since General Electric has continued with the buried conduit project, EES felt obligated to investigate a buried cable approach using modulation/demodulation techniques over coaxial cable or using frequency multiplex techniques with fiber optics cable between the sites.

COMMUMICATION ALTERNATIVES FOR LOUISVILLE, KENTUCKY

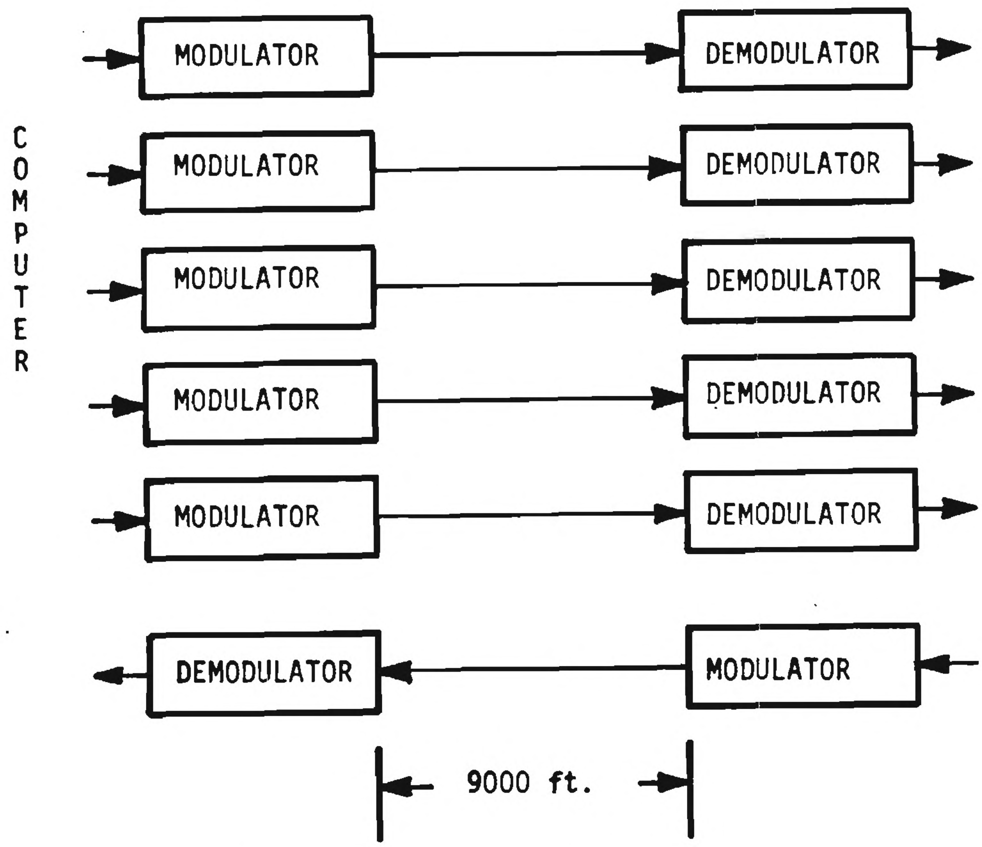
Two configurations have been identified which will support the desired communications at the Louisville facility. Both configurations utilize equipment commonly used for long distance distribution of television video signals. The modulation technique employed is Frequency Modulation (FM), which offers inherent noise immunity, and the systems have been designed to provide as a minimum a 60 dB signal-to-noise ratio (SNR). It is difficult to relate this SNR to traditional data reliability, such as bit error rate (BER).

However, for the standard television video, this SNR exceeds that available in the originating studio by five to ten dB. In summary, this is an exceptionally high quality signal.

The first configuration is shown in figure 3 below. Each data channel consists of a modulator-demodulator pair connected by individual coaxial cables. The use of multiple cables is motivated by:

(1) the need to have total commonality in the modulators and demodulators, and

(2) the need to eliminate the use of active devices in the lines.



BLOCK DIAGRAM OF A MULTI-LINE SYSTEM

FIGURE 3

Commonality in the modulator-demodulator equipment is achieved through the use of a single carrier frequency. Thus, maintenance can be reduced to module or unit replacement, and the required inventory is reduced to an absolute minimum.

The cost of implementing this system may be divided into three elements: equipment, line installation, and system integration. The equipment cost is $29,200 and includes the modulators, the cables, the demodulators, and the various cable fittings.

Three approaches to line installation have been explored. The first approach is to bury the cable, at a cost of $13,800, based upon typical trenching costs for the cable television industry. The second approach is aerial cabling on existing poles, at a cost of $9,900. The third approach is aerial cabling where it is necessary to install support poles. The cost for this is $26,160 and, as in the previous aerial approach, the cost estimate is based on typical cable television installation costs.

The cost is summarized in figure 4 in tabular form on the following page.

CABLE INSTALLATION TECHNIQUE / ITEM	BURIED CABLE	AERIAL ON EXISTING POLES	AERIAL AND INSTALL POLES
EQUIPMENT	←	$29,000	→
INSTALLATION	$13,800	$9,960	$26,160
INTEGRATION	←	$12,500	→

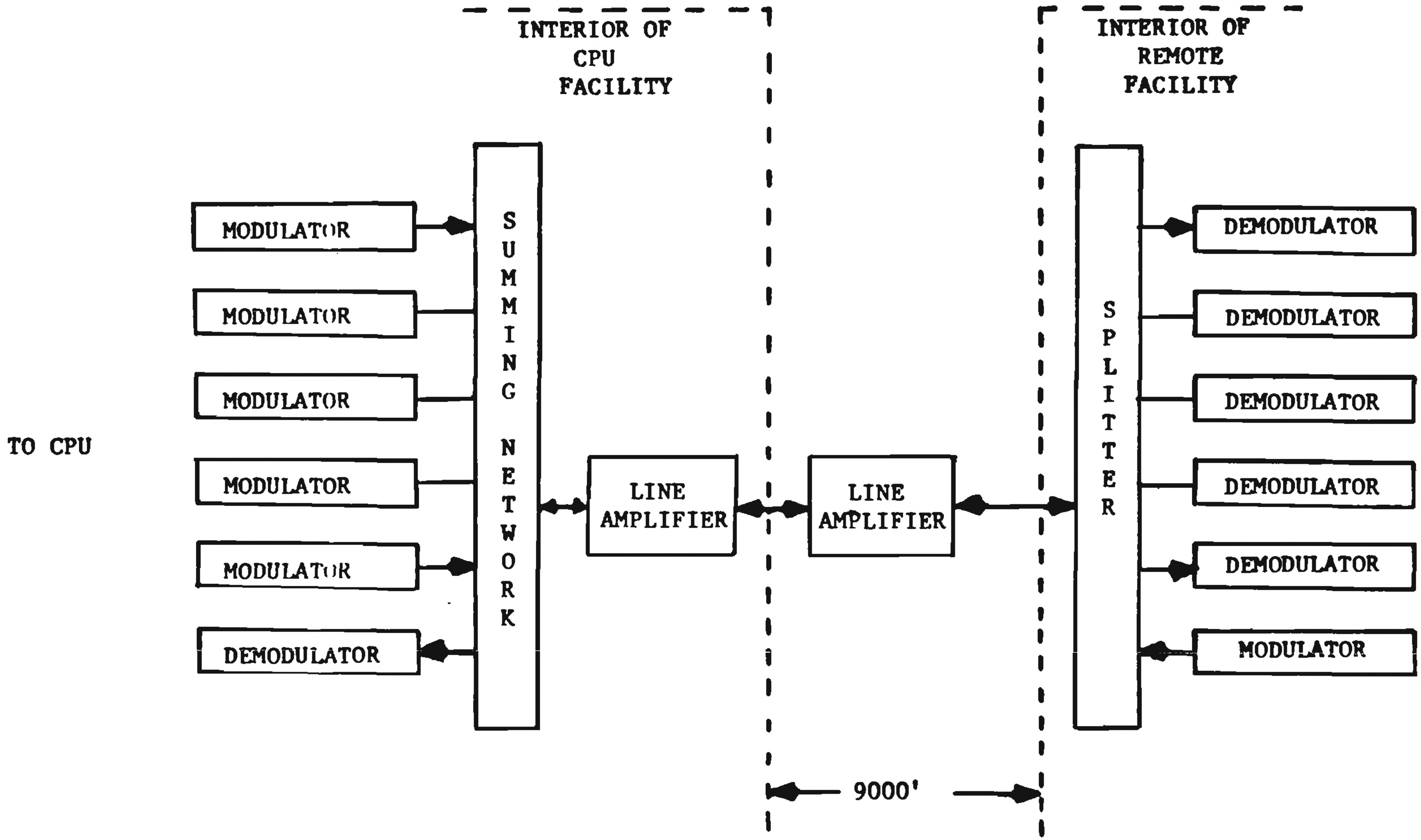
COST FACTORS FOR THE MULTI-LINE IMPLEMENTATION

FIGURE 4

By eliminating active components in the transmission line, system reliability is significantly increased with the estimate of 10 to 20 years for cable life.

The second approach is defined by figure 5 on page 16, and pricing information is shown in figure 6 on page 17. Here the outgoing data channels cover the frequency range of 69 to 139 megahertz, and the incoming data channel is centered at 19 megahertz. In each case transmission is by a frequency modulated carrier occupying a 14 megahertz bandwidth.

The frequency division multiplexing (FDM) is performed by the summing network at the central processing facility, and because of the losses introduced by this device and the splitter at the other end of the line, it is necessary to use line amplifiers. The use of these devices does reduce the reliability of the system; however, the approach used minimizes the degradation. One of the line amplifiers is installed in the central processing facility, and it is therefore not subjected to the external environmental stresses. An advantage offered by the FDM approach is that only one 3/4-inch cable is required, resulting in a noticeable advantage for serial implementation.



BLOCK DIAGRAM OF A FREQUENCY DIVISION MULTIPLEXED (FDM) SYSTEM

FIGURE 5

CABLE INSTALLATION TECHNIQUE / ITEM	BURIED CABLE	AERIAL ON EXISTING POLES	AERIAL AND INSTALL POLES
EQUIPMENT	←	$22,800	→
INSTALLATION	$13,800	$1900	$15,000
INTEGRATION	←	$12,500	→

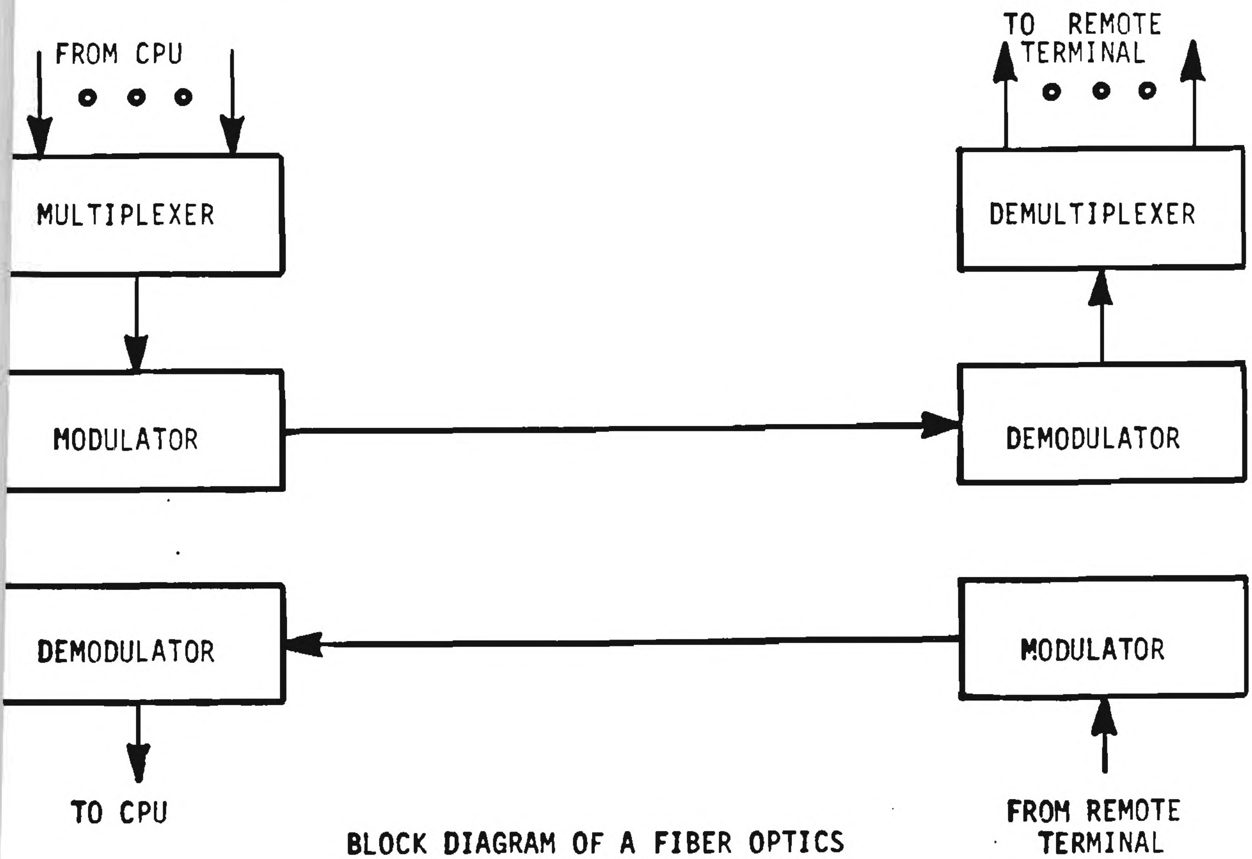
COST OF FREQUENCY DIVISION MULTIPLEXED (FDM) SYSTEM

FIGURE 6

FIBER OPTICS DATA TRANSMISSION SYSTEM

The preferred approach for a fiber optics data transmission system is shown in figure 7 below. The five data lines from the central processing facility are multiplexed into a single bit stream and then encoded by the laser modulator. At the site of the remote terminal the composite signal is demodulated and then the bit stream is separated into the original five channels. In the reverse direction, the single data channel from the remote terminal drives a modulator directly, and the output of the demodulator at the central processing facility directly feeds the central processor input port.

The cost associated with this configuration is presented in figure 8 on the following page.



BLOCK DIAGRAM OF A FIBER OPTICS
DATA TRANSMISSION SYSTEM
FIGURE 7

CABLE INSTALLATION TECHNIQUE / ITEM	BURIED	AERIAL ON EXISTING POLES	AERIAL AND INSTALL POLES
EQUIPMENT	←	$36,800	→
INSTALLATION	$13,800	$9,960	$26,160
INTEGRATION	←	$12,500	→

FIBER OPTICS IMPLEMENTATION COST
FIGURE 8

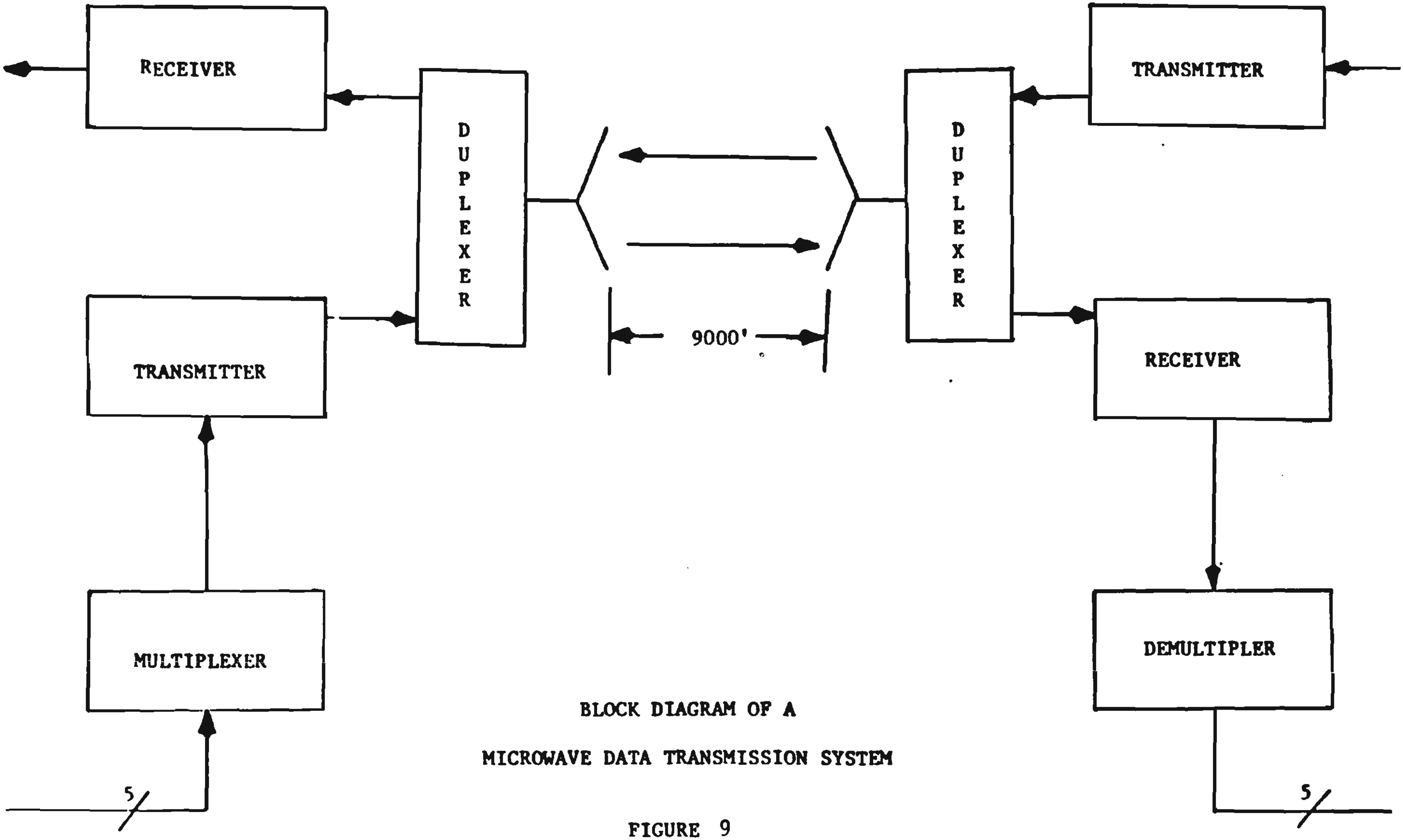
A fiber optics system offers considerable expansion capability with the limiting factors being primarily the multiplexer - demultiplexer characteristics and the characteristics of the optical cable. The cost figures for the equipment in the above table reflect the use of a moderate performance cable. A cable which can support data rates in the multiple megabits per second may be employed for an additional cost of $3,000.

Another attractive feature of the fiber optics system is its immunity to electrical noise.

MICROWAVE DATA TRANSMISSION SYSTEM

The recommended approach for a microwave data transmission system is shown in figure 9 on page 21. Actual implementation of such a system must be preceded by the licensing activities described in Appendix (A), which include an interference analysis. Due to the data rates involved, this system will of necessity be a wide bandwidth system, a feature which could put the granting of a license in question. The path length here is relatively short for a microwave system, and the additional demand for a large bandwidth could, depending upon the demand for channels in the area, cause the license request to be denied.

The costs incurred in implementing such a system are summarized on the next page with system interconnection illustrated in figure 10 on page 24. Note that these figures do not include any expenditures associated with the licensing activity.



BLOCK DIAGRAM OF A

MICROWAVE DATA TRANSMISSION SYSTEM

FIGURE 9

COST TO IMPLEMENT KENTUCKY MICROWAVE LINK

ITEM	COST
Radio Equipment (transmitters, receivers, duplexers, antennas, and multiplexers)	$49,000
System Installation*	

* This item does not include the FCC required interference analysis, filing an application for the required FCC license, or any architectural modifications to the facilities required to route cables or mount antennas.

FIGURE 10

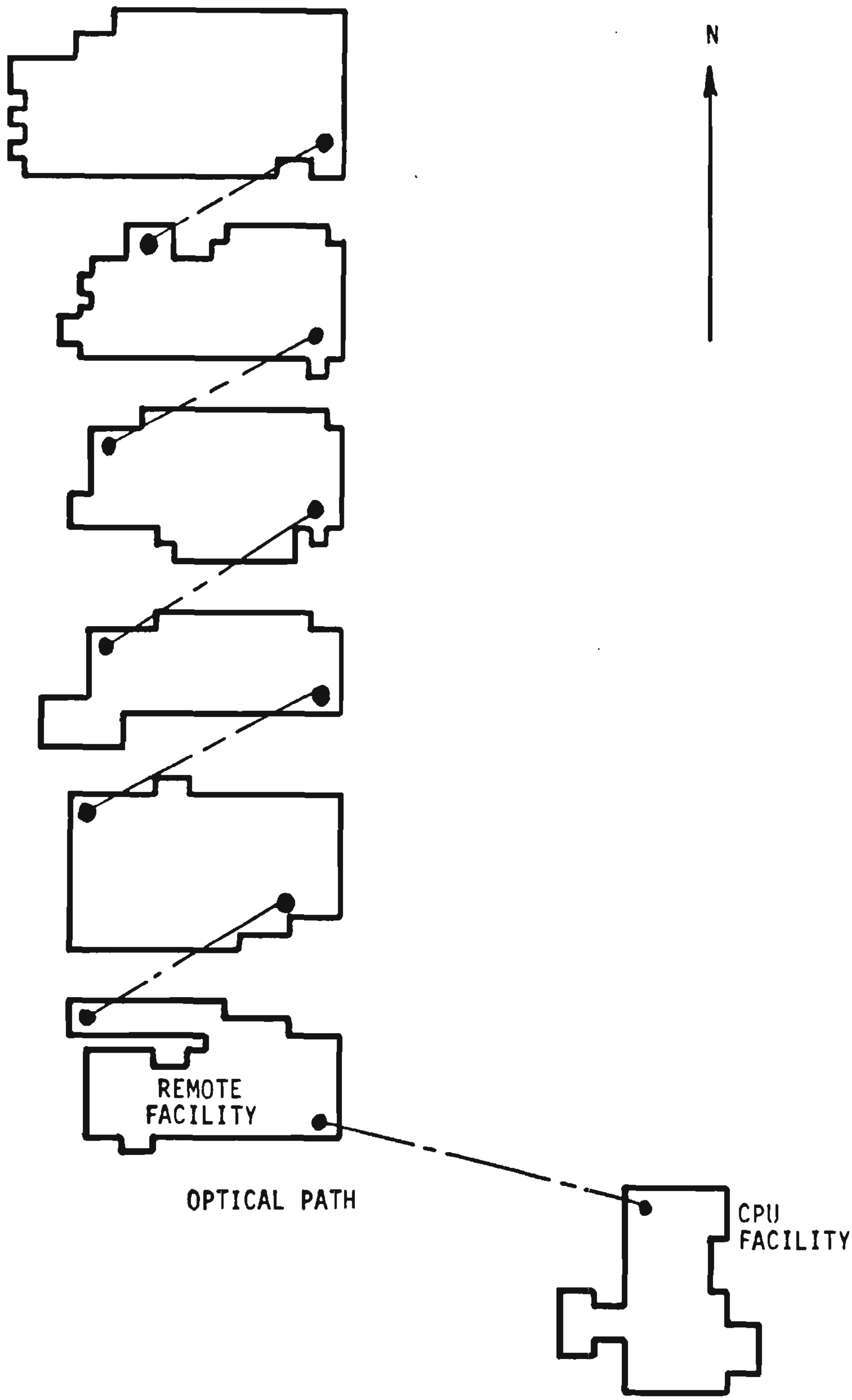
USE OF OPTICAL COMMUNICATION LINKS

Optical communication links could be employed for short paths, but two limitations should be addressed: platform stability and weather effects.

Manufacturer supplied data indicates that a bit error rate (BER) of 1^{-10} is achievable over a 200 meter path in clear weather with a beam divergence of 30 milliradians. The beam divergence indicates that the platform motion should be restrained to plus or minus three meters in the plane perpendicular to the direction of propagation to achieve the stated BER. This does not appear to be a particularly stringent requirement, and if platform motion can be restricted then the beam divergence could be decreased, leading to a lower BER.

Weather, particularly fog, has an extremely adverse effect on optical systems of this type. In general, the transmission coefficient changes by approximately two orders of magnitude between a "clear" atmosphere and an atmosphere of "moderate fog". Such a change would bring the BER from 1^{-10} to 0.5, assuming that a beam divergence of 30 milliradians had been employed for a 200 meter path. If, due to increased platform stability, a divergence of five milliradians is used, then the BER would probably drop to a value of 6^{-5}.

A possible layout for an optical communications system is shown in figure 11 on page 24. At least two points should be noted in the layout of such links.



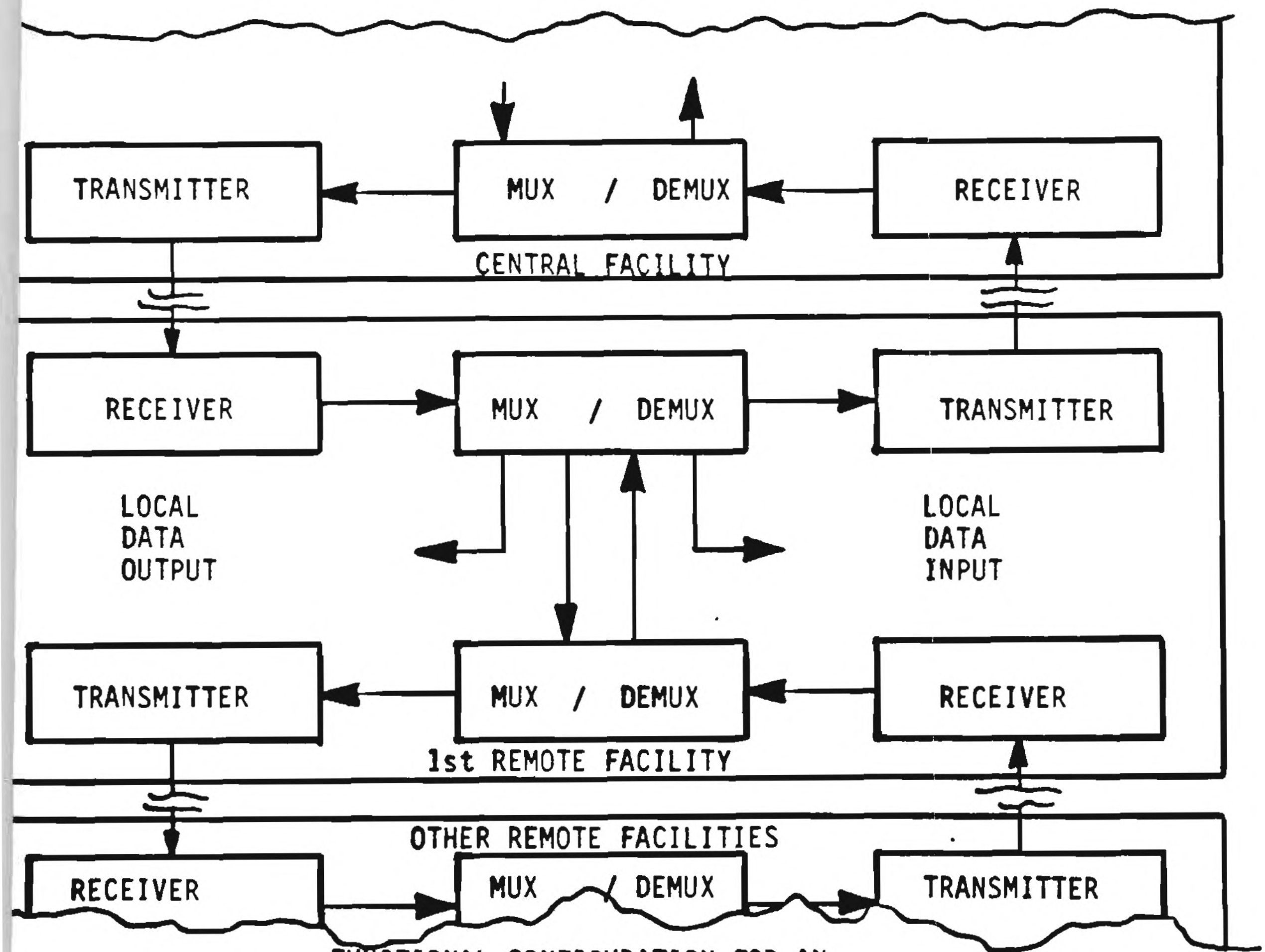
LAYOUT OF AN OPTICAL TRANSMISSION SYSTEM
LOUISVILLE KENTUCKY
FIGURE 11

(1) Avoid, when possible, paths in which the sun is on or near the quipment axis.

(2) If possible, eliminate highly reflective surfaces along the path.

The hardware arrangement for this implementation is illustrated below with he cost estimates tabulated below:

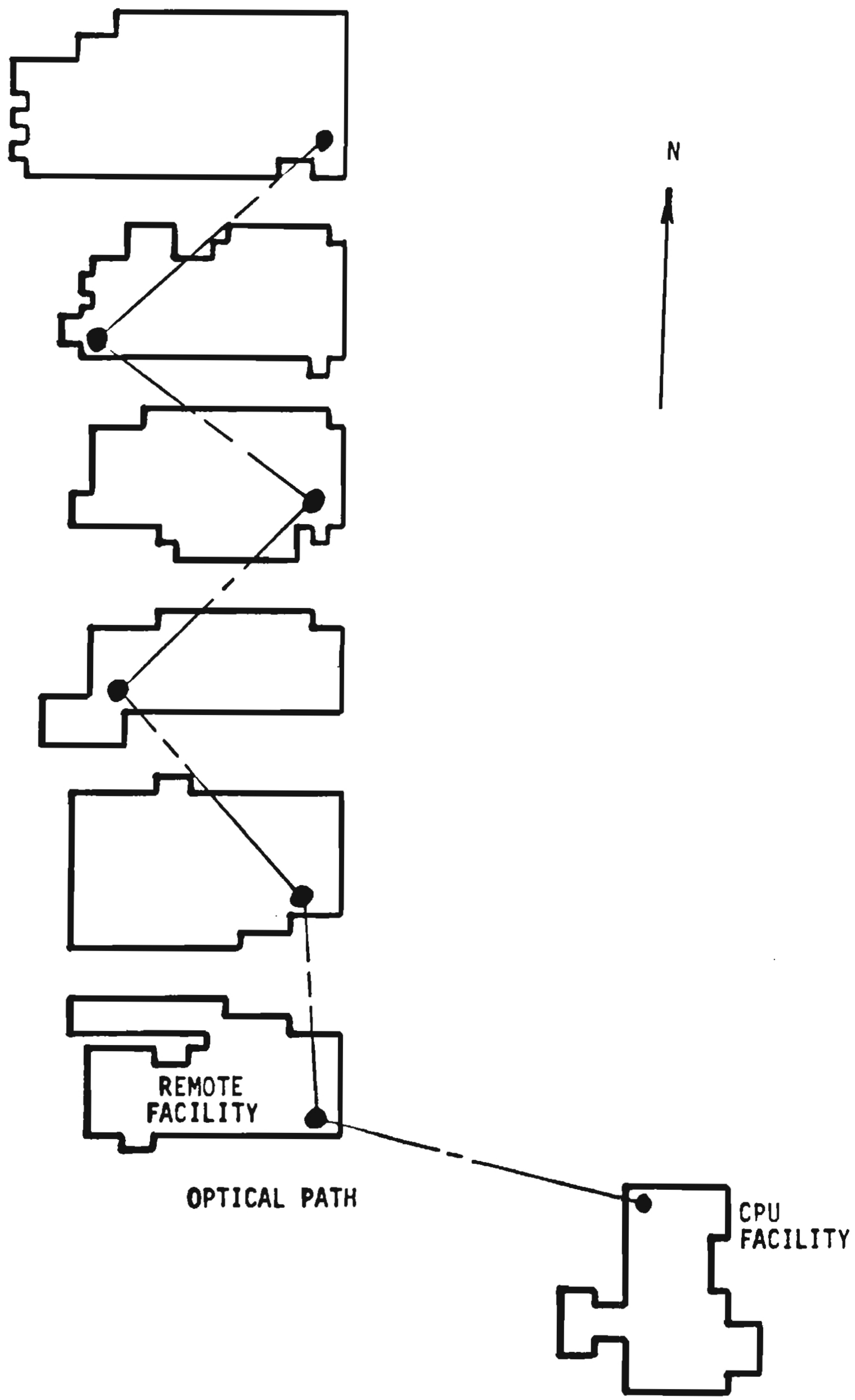
Optical Equipment:	$ 24,000
Multiplexing Equipment:	$132,000



FUNCTIONAL CONFIGURATION FOR AN OPTICAL COMMUNICATION SYSTEM
FIGURE 12

For the layout shown in figure 11 on page 24, the connection within a given building between a multiplexer and a demultiplexer would commonly use standard coaxial cable at a cost of approximately $160/1000 feet. One such cable would be required for each channel to be interconnected. Such an arrangement would be suitable if the cable run between the demultiplexer and the multiplexer is no more than a few hundred feet. For longer runs, it would be necessary to use broadband line amplifiers, one in each line, at a cost of approximately $500 each. An alternate approach is shown in figure 13 on page 27. In this configuration, a single optical platform is required at each building, and all of the multiplexing and demultiplexing equipment may be located so that interconnection will involve very short lengths of line at unnoticable cost.

One additional point should be mentioned about the arrangement shown in figure 12 on page 25. The previously quoted prices for multiplexing/-demultiplexing equipment apply to six channel units which can accommodate a maximum transmission speed of 12.536 MB/s (Megabits Per Second). On the outbound path, central-to-remotes, this capacity is fully utilized to support a single graphics channel; therefore, it is possible to use this arrangement to distribute only a single image at a time. If local refresh and multipoint address recognition is available at each remote site, then it is possible to provide multiple images over the network through the use of a poling arrangement. If such a system is not available, then it is necessary to create a point-to-point arrangement through the use of a different multiplexer arrangement.



LAYOUT OF AN OPTICAL TRANSMISSION SYSTEM
LOUISVILLE KENTUCKY
FIGURE 13

The arrangement to achieve virtual circuits between the CPU and the remote ·rminals is shown in figure 14 below. In comparison with the earlier ›nfiguration illustrated in figure 12 on page 25, there is more ıltiplexing/demultiplexing equipment, and it is important to realize that ›me of the additional equipment is higher in speed than the equipment used in ıe previous arrangement. The combination of more equipment and higher speed ill lead to a significantly higher cost for this arrangement.

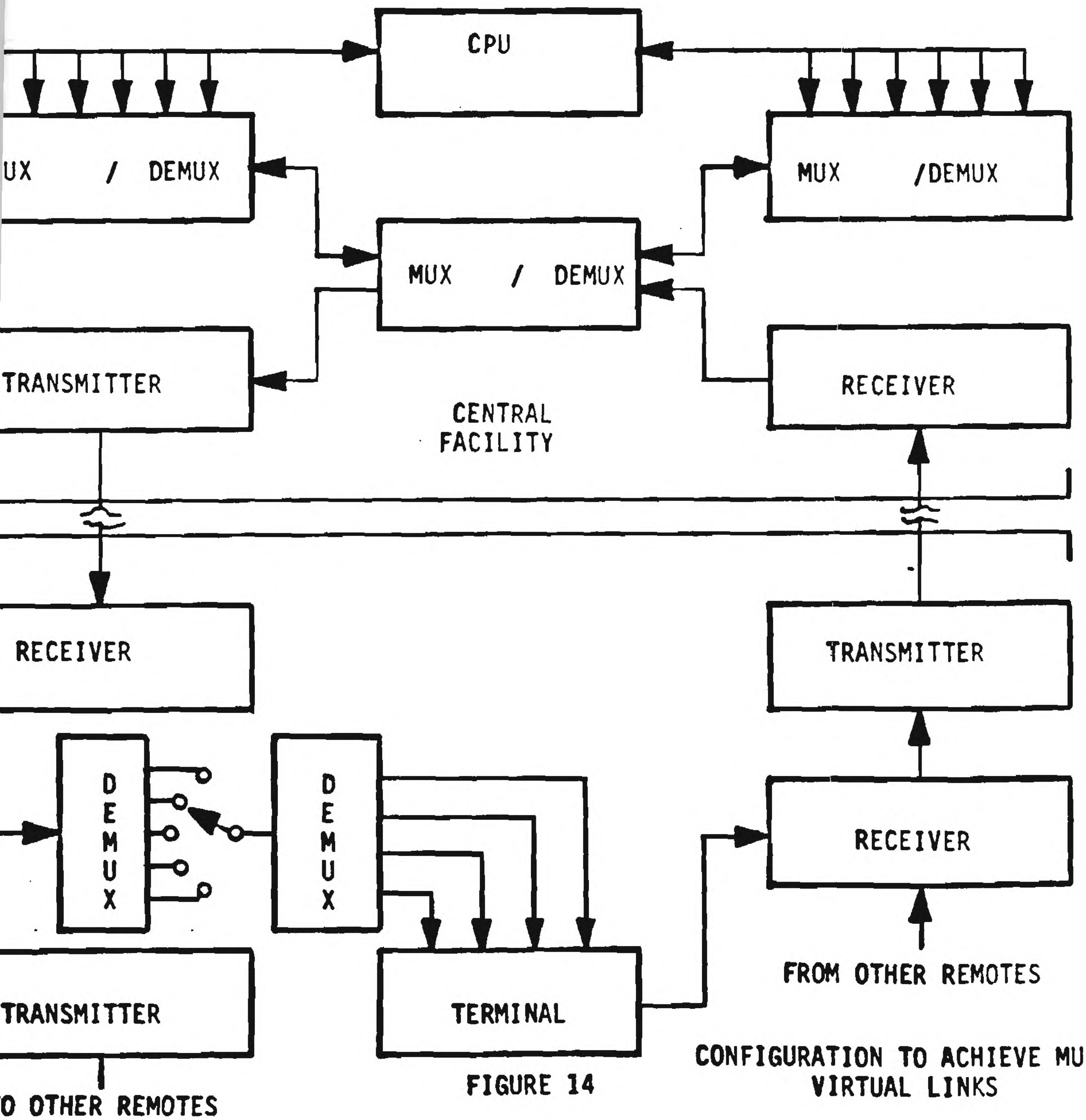


FIGURE 14

CONFIGURATION TO ACHIEVE MULTIPLE VIRTUAL LINKS

COMMUNICATIONS ALTERNATIVES FOR CLEVELAND, OHIO

Five alternative communication systems have been examined for use at the Cleveland, Ohio, site, including:

(1) the use of leased telephone company lines,

(2) the use of a private cable system, either RF or optical,

(3) the use of laser communications for the shorter distances and the use of microwave equipment for the longer distances,

(4) the use of a private microwave system, and

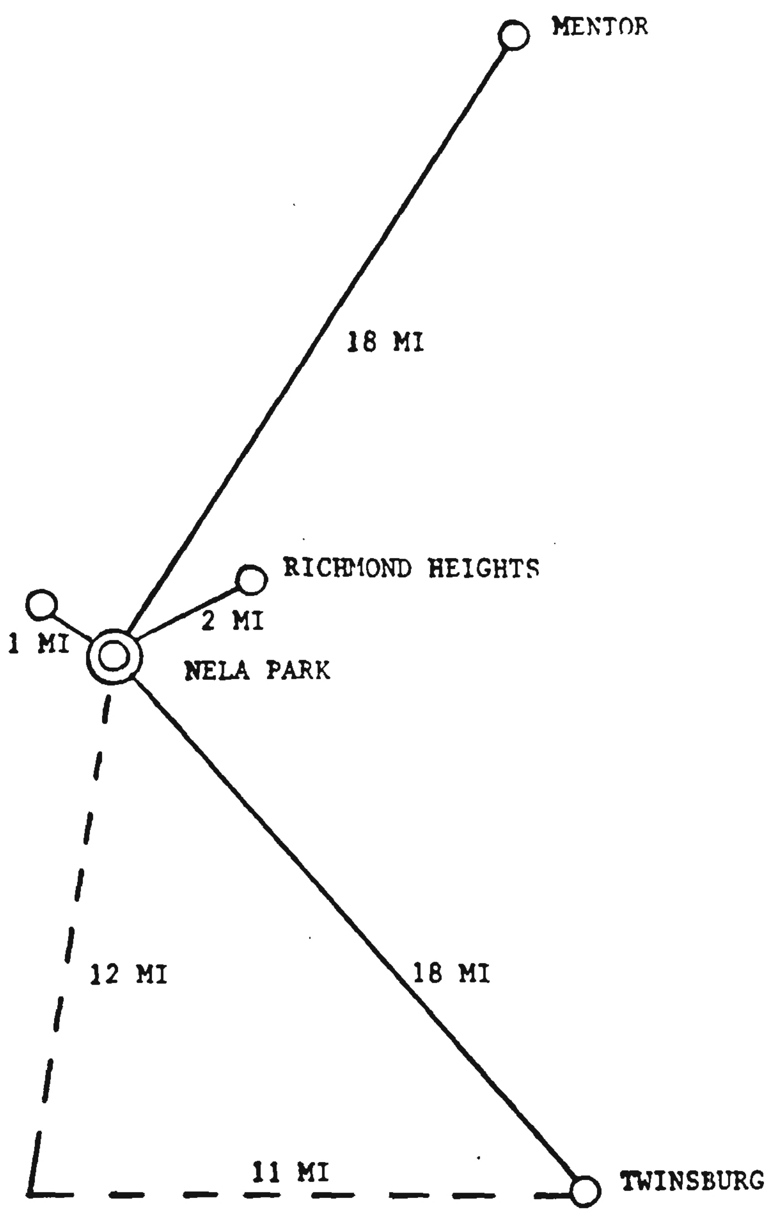
(5) the use of a mixed system employing both millimeter and microwave equipment.

In the first approach, the use of leased lines, the telephone company installs the lines and assumes the responsibility for maintenance and end-to-end data integrity. The minimum line required for the data system is one which the telephone company uses for 230.40 KB/s transmission. Eight of these lines would be required to support the data transmission. The lease fee for one of these lines is $2,218.50 per month for a 25-mile line. The installation fee is $480.00 per line, and the delivery time is six to eighteen months. Such a system can be expanded by adding additional lines.

It is technically feasible to install a private cable system using either RF or optical signaling. This approach is reasonable for the shorter paths of one and two miles, and it can provide considerable expansion capacity. The cost of such a system is discussed in the Kentucky site approaches, but it is assumed that the company owns all of the property along the path at the Louisville facility. Therefore, it would not be necessary to purchase land 'or line installation or to lease space on existing power/telephone poles. ɩoth the leased line system and the private cable system are expensive, and ɩhe exact cost would be subject to negotiation.

Another approach, which is potentially suitable for the short lengths of ɔne or two miles, is the use of laser communications. Lasers do not require ɩicensing, permit extensive expansion without altering the channel equipment, ɔut are disrupted by fog. Given the close proximity of Lake Erie and the ɜxpectation that fog is common in the area, this approach has been eliminated.

The geometry which would apply for a microwave system is shown in figure 15 on page 31. A limited review of the terrain in the service area indicates that not only will the Nela Park - Twinsburg communication path be the most demanding technically, but it will also be a major expense. This factor is illustrated in figure 16 on page 33.



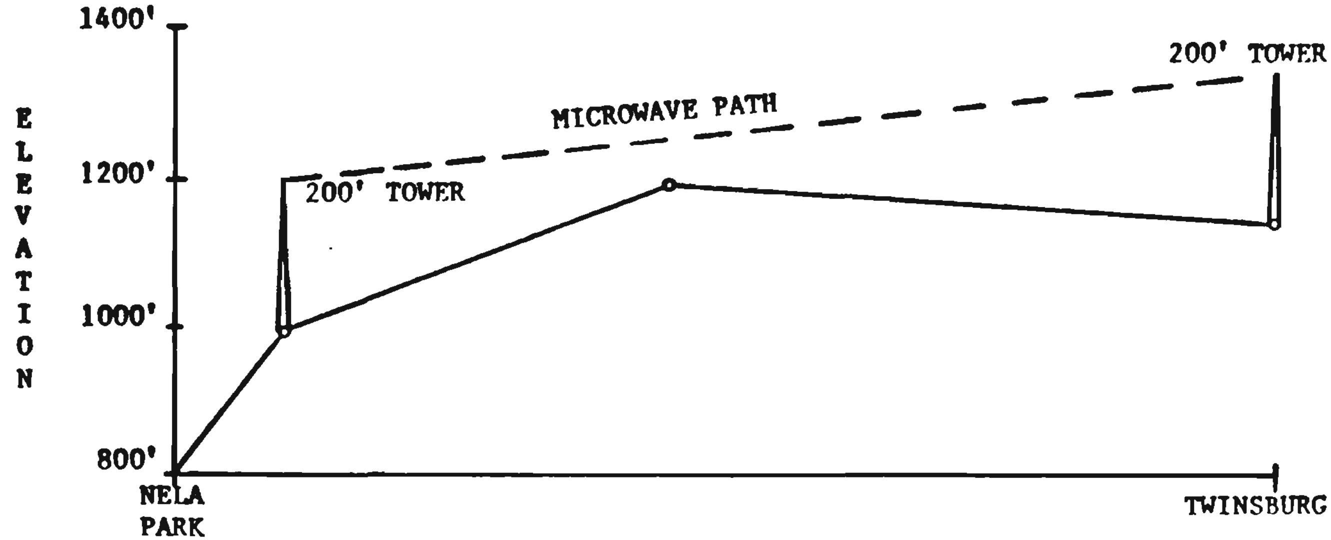
GEOGRAPHICAL LAYOUT OF POINTS IN
THE MICROWAVE SYSTEM

FIGURE 15

Microwave systems depend upon line of sight (LOS) propagation. Figure 6 on page 33 shows that such a system can be achieved for the Nela Park - Twinsburg path by installing two 200 foot towers. One tower is located at the Twinsburg facility, and the other tower is to be located approximately two miles southeast of the Nela Park facility. The cost of each of these towers is approximately $20,000. In addition, the tower near Nela Park will require land acquisition. The quoted price is for a guyed tower, and such a tower would require approximately 0.7 acres to accomodate the tower and its guying assemblies. Another factor to be considered in tower installation is the required zoning clearances. In some cases, this consideration increases the amount of land required around the tower.

The preliminary terrain survey indicates that all of the other paths can be served with very minimal antenna/tower installations. One problem that may arise from serving multiple remote sites from the central facility at Nela Park is signal congestion. In theory, General Electric could request different frequency assignments for each path, and resolve the interference problem at Nela Park; however, it is highly unlikely that such a request would be granted within the conventional microwave channels.

A possible solution to this potential interference problem would be to use both microwave and millimeter wave frequencies. The microwave channels could be used for the long links (Mentor and Twinsburg facilities). The millimeter channels could be used for the short links (Richmond Heights and East 152nd Street facilities).



TERRAIN PROFILE FOR THE NELA PARK-
TWINSBURG MICROWAVE LINK

FIGURE 16

Discussions with General Electric personnel reveal that the area southeast f the Nela Park facility may not be suitable for tower installation. herefore, an alternative, depicted by dashed lines, is shown in figure 15 on age 31.

A ridge containing a variety of communications towers has been observed pproximately 12 miles south-southwest of Nela Park. It would be possible to se a repeater at this location to link Nela Park and Twinsburg. Two ap-roaches are possible: private usage or shared facilities. In the private sage approach, General Electric would purchase land and erect a tower. A limited terrain review indicates that the tower could be approximately 50 feet all. A 100- to 200- foot tower would still be required at the Twinsburg site o overcome terrain obstructions.

The FCC permits the shared use of radio facilities; therefore, it may be practical to investigate the use of existing tower/facilities on the ridge. This approach eliminates the need to purchase land and erect a tower at a re-mote location. Since the fee for use of tower space is generally proportional to mounting height, and since the link does not require an extremely high an-tenna, this could be a cost effective alternative to private development.

COST ESTIMATES FOR FOUR OF THE APPROACHES DISCUSSED ABOVE:

:ASED LINE SYSTEM

1) LINE LEASE FEE:	$17,748 PER MONTH	$212,976 PER YEAR
2) MODEM EQUIPMENT:		27,200
3) INSTALLATION COST:		3,840
)TAL FOR ONE YEAR		$244,016

ICROWAVE SYSTEM

1) RADIO EQUIPMENT:	$100,000
2) MULTIPLEX EQUIPMENT:	96,000
3) TOWERS:	40,000
4) INSTALLATION COST:	20,000
)TAL	$256,000

ICROWAVE AND FIBER OPTICS CABLE SYSTEM

1) RADIO EQUIPMENT:	$ 50,000
2) MULTIPLEX EQUIPMENT:	96,000
3) FIBER OPTICS EQUIPMENT:	23,100
4) TOWERS:	40,000
5) POLE FEES:	NEGOTIABLE
6) INSTALLATION COST:	17,000
'OTAL	$226,100 PLUS POLE FEES

IICROWAVE AND MILLIMETER WAVE SYSTEM

(1) MICROWAVE EQUIPMENT:	$ 50,000
(2) MULTIPLEX EQUIPMENT:	96,000
(3) MILLIMETER EQUIPMENT:	106,000
(4) TOWERS:	40,000
(5) INSTALLATION COST:	25,000
TOTAL	$317,000

FIGURE 17

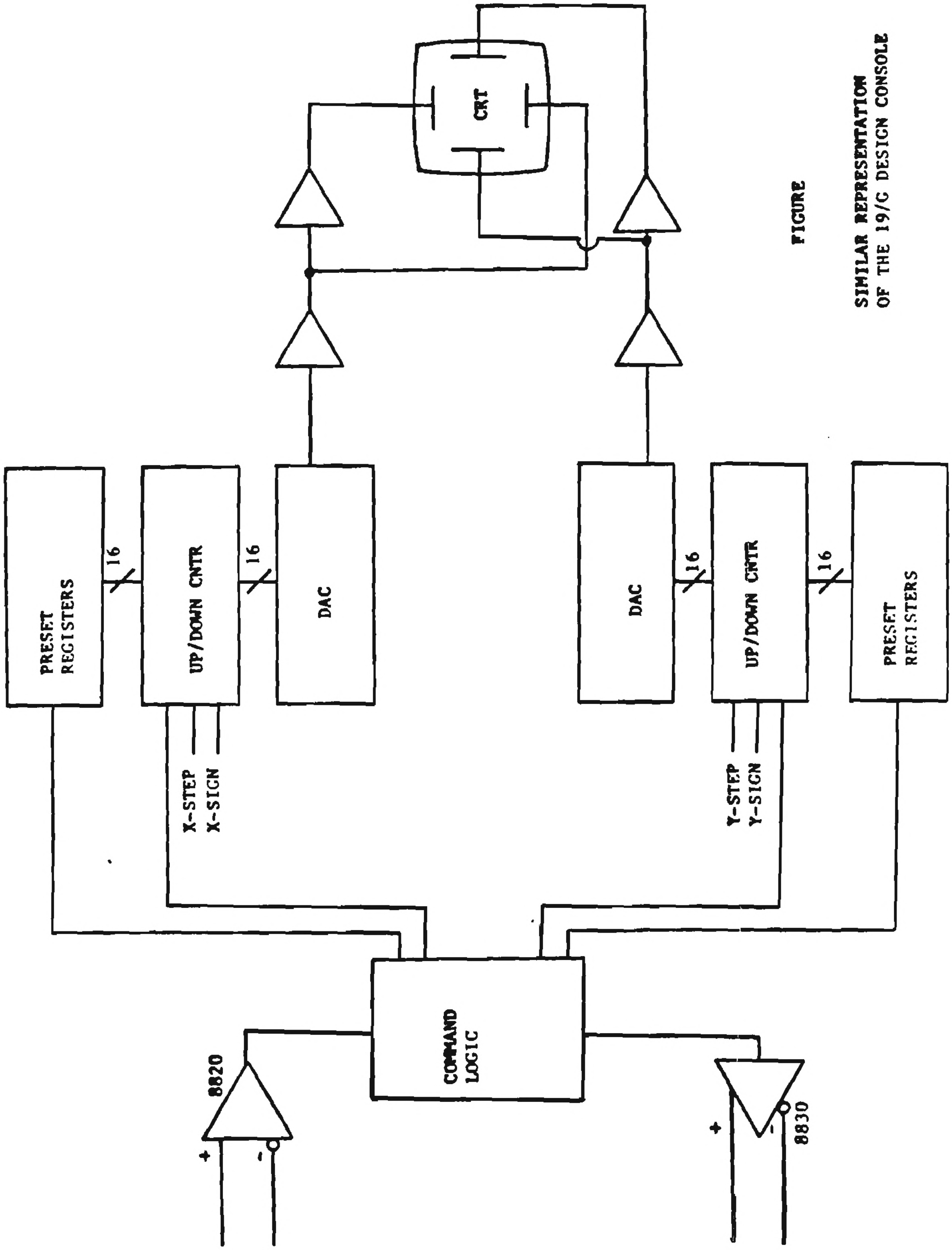
IOS / 19/G DESIGN CONSOLE COMMUNICATIONS

The IOS interface handles all designer system communications with the nteracts plus the generation of vectoring information for incrementally riving the stepping motors of the plotter and the counters on the interact IS and the beam on the storage tube. The drive pulses are the output of a icroprogrammable processor located on the IOS interface board. This icroprocessor contains the algorithms which generate the moving and drawing ommands by processing the vector data sent from the design console.

The IOS interface board employs serial communication at a data rate of 500 Hz. The format of the input/output communication word consists of one start it (pre-information), 16 bits of information, and one stop bit post-information) .

The microprogrammed processor receives the vectoring information over the ata channel of the Nova 1200 minicomputer. When the IOS Interface is ontrolling the CRT display, the CRT drawing rate is governed only by the hroughput of the microprogrammed processor on the IOS Interface. Commands re sent by the IOS board to change the cursor origin or to control the other ncillary equipment at the 19/G Design Console, such as the digitizer pad and he plotter. A command must precede the vector information to provide an riginating point for the vector. If any other attribute is necessary to odify the drawing technique or to change the originating point of a vector, nother command must precede the vector information.

Figure 18 on the following page provides a circuit diagram that illustrates a similar relationship between the vector pulse stream provided by the IOS board and the CRT that is part of the 19/G Design Console. This configuration shows the necessity of providing data integrity between the IOS board and the 19/G Design Console; the X-step & X-sign, and the Y-step & Y-sign must be corollated to provide proper vector action.



FIGURE

SIMILAR REPRESENTATION OF THE 19/G DESIGN CONSOLE

As can be seen in figure 18 the vector pulses provide the only means of rawing the lines on the CRT after the originating coordiates have been sent o the 19/G Design Console. The commands stream sent by the IOS board ontains the data and commands that loads the up/down counters with the X and origin coordinates. First the IOS sends the commands to initialize the rigin of the line; then the IOS begins drawing the lines from the present rigin. Only when a new origin is needed is it necessary to send new oordinates by way of the command line.

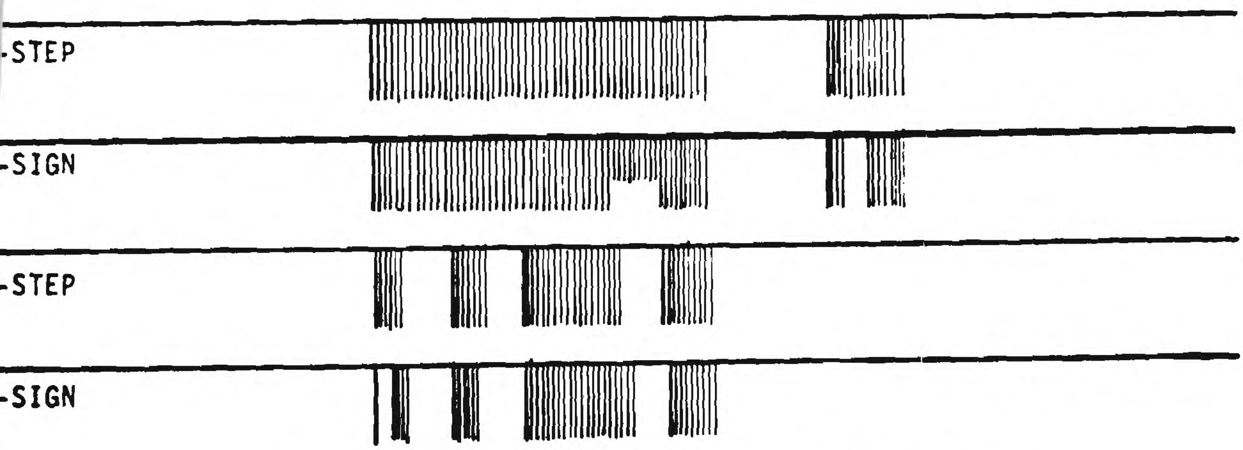
Figure 19 on page 39 illustrates the patterns that may be observed on the utput of the X,Y step or X,Y sign line-receivers(8820 TTL gate) during a icture drawing session, while figure 20 on page 41 illustrates the elationship of the command to vector information.

During different phases of "repaint," the time to repaint the screen due to processor time may vary. For example, if view 2 is previously drawn, the system will repaint the view very quickly upon command. If another view is required, the time to repaint will be increased significantly due to the intervector calculations the system performs in displaying another view. Strangely, when the system is required to rotate a figure on the same axis so as to cause the same face to remain in view, it computes a completely new data base and then repaints as for a same-view repaint.

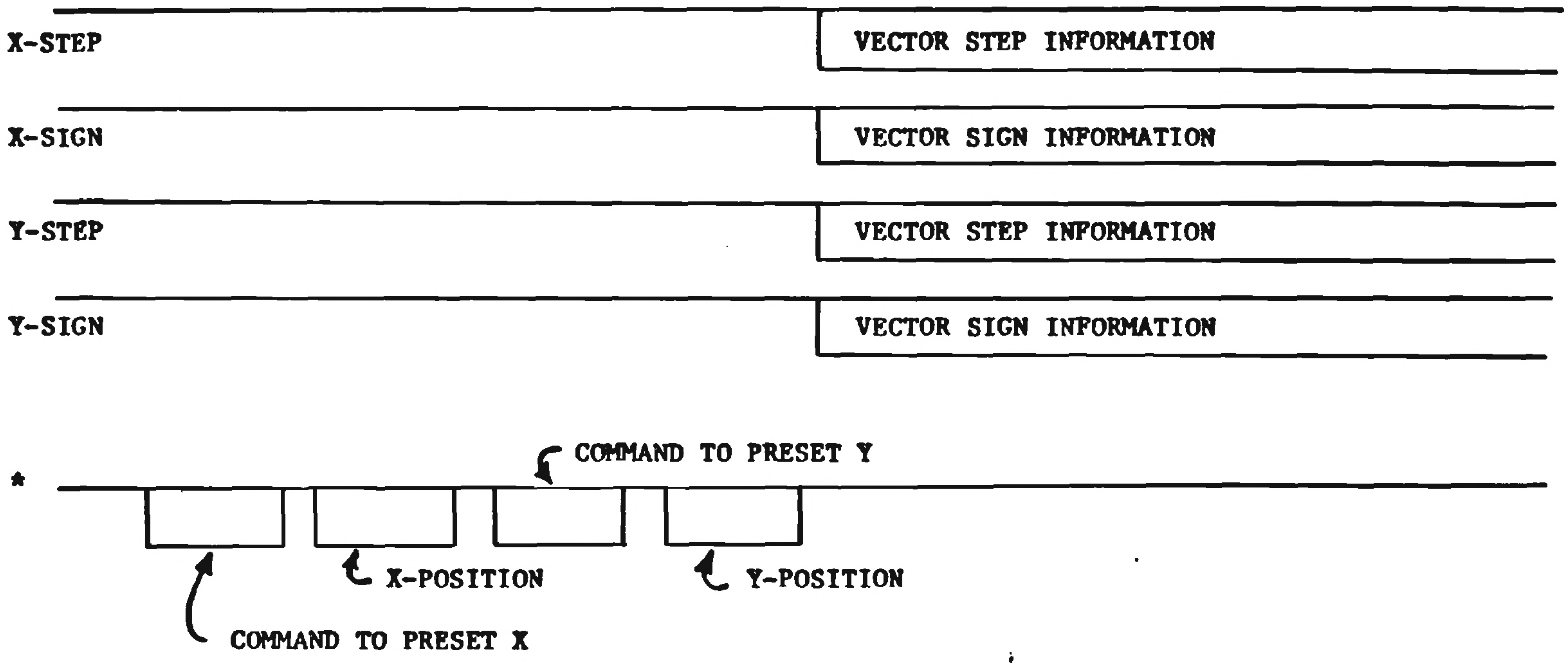
ADDED ALTERNATIVE TO STRICT COMMUNICATIONS

Another added alternative to the long distance interface is to remote a)VA 1200 minicomputer with an IOS board to provide the controls for the 19/G ɜsign Console and enough resident software to provide the communications ɜtween the computer and also to provide some low level vector manipulations. nly when major updates are necessary would a data transfer of data bases be ecessary from the remote site to the mainframe or from the mainframe to the emote site.

This approach with a remote NOVA 1200 would require a high data transfer ·ate, but less than is required by the present analog or digital approach. This high rate, even though lower than any previously mentioned rate, would minimize operator fatigue and system overhead. This technique would also reduce the stringent communication network that is necessary to transfer the control pulses that are required to draw vectors on the 19/G Design Console.



X-Y VECTOR CONTROL FOR TYPICAL CURSOR MOVEMENT
FIGURE 19



RELATIONSHIP BETWEEN COMMANDS SENT BY THE IOS TO THE 19G SCOPE AND THE VECTOR PULSE INFORMATION.

* NOTE: THE ORDER OF THE FIRST TWO AND SECOND TWO COMMAND WORDS IS NOT DEFINITE

FIGURE 20

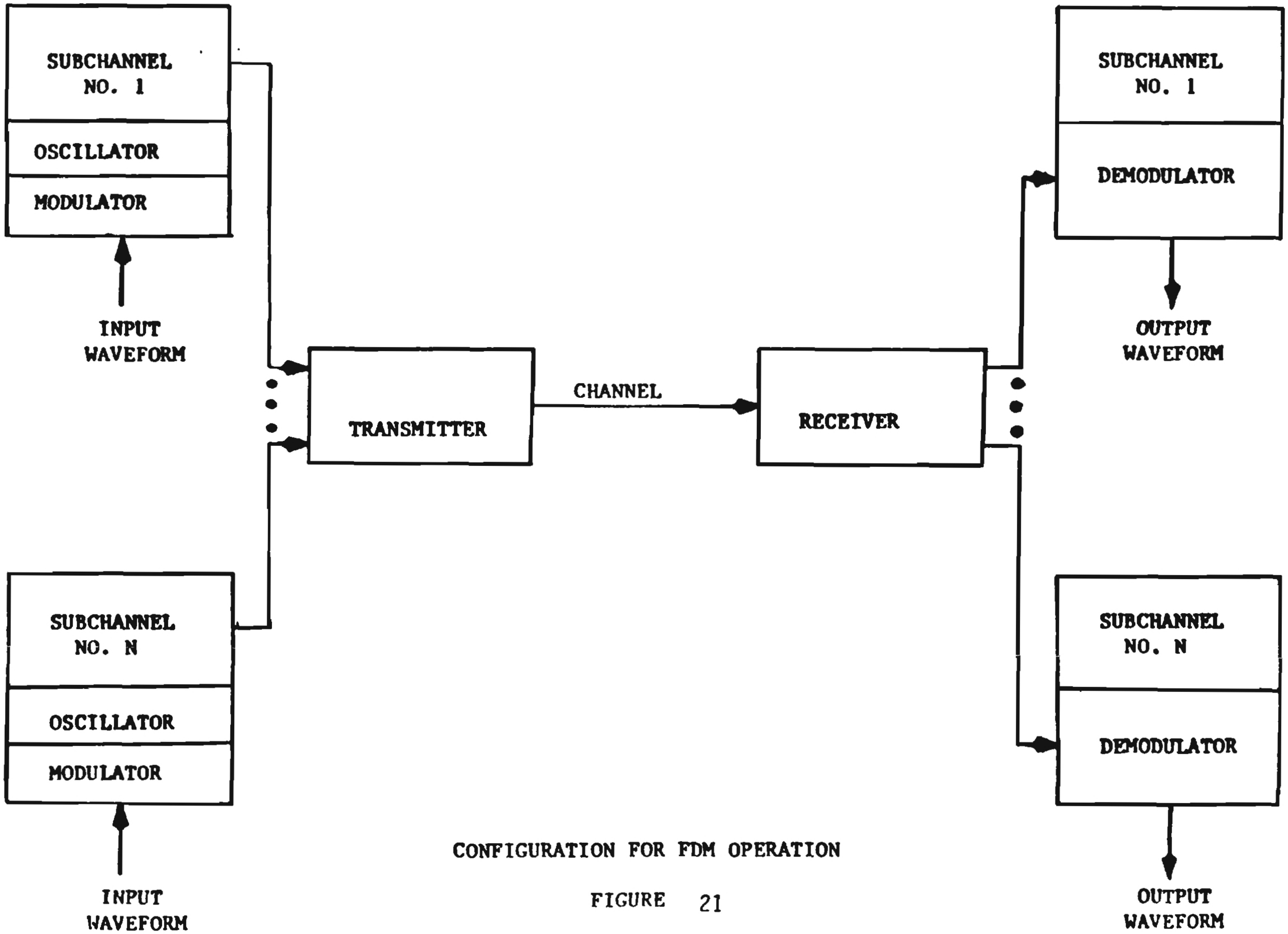
CONCLUSION

Many of the preceding comments suggest the use of strictly analog trans-ission techniques since the involved waveforms are not the conventional data treams. Therefore, both pre-multiplexing and post-demultiplexing processing ould be required to properly format the "data stream." By using analog echniques, each waveform is transmitted over a separate analog channel which s totally independent of the events on any other analog channel. The basic echnique for providing this analog transmission of multiple waveforms is requency division multiplexing (FDM).

The radio frequency (RF) cable systems described elsewhere in this report re basically FDM approaches. In one case, each waveform is associated with a eparate carrier frequency, and the modulated carriers are combined and ropagated along a single coaxial cable. In the other case, a single carrier requency is employed, and the various modulated carriers progagate on eparate coaxial cables.

It is also possible to use FDM techniques with microwave and laser systems. Figure 21 on page 43 shows how this would be done. Each subcarrier s independently modulated, and the outputs of all of the subcarrier units are combined to produce the composite baseband signal which modulates the ransmitter. The transmitter's output propagates through the channel, which ay be either the atmosphere for microwave, atmospheric laser systems, or ptical cables for guided laser on LED systems.

Conceptually, this approach is straight-forward; however, due to the nature of the various waveforms to be transmitted, subchannel equipment does



CONFIGURATION FOR FDM OPERATION

FIGURE 21

ot appear to be available as a standard off-the-shelf product. It is ossible to readily acquire the components necessary to build the subchannel quipment. The major issue to be settled for such an implementation is the ype of modulation to be employed by the subchannel units.

The modulation candidates for the subcarrier systems fall into two broad ategories: linear and nonlinear modulations. The linear techniques include mplitude modulation (AM), double sideband modulation (DSB), single sideband odulation (SSB), and vestigial sideband modulation (VSB). The AM system is he easiest to implement, but it requires large amounts of signal band width nd signal power to reduce noise related errors.

The sideband techniques, DSB, SSB, and VSB, all reduce the signal power equirements compared to the AM approach; however, the implementation lifficulty is increased relative to that associated with the AM system. The SB approach requires the same bandwidth as AM, SSB requires half the andwidth of AM, and VSB requires bandwidth that lies betweem that of DSB amd SSB.

The candidate nonlinear modulations are frequency modulation (FM) and phase modulation (PM). In general, nonlinear modulation tends to achieve a high degree of noise immunity at the expense of increased signal bandwidth. The exception to this is binary phase shift keying (BPSK). BPSK has the same bandwidth as AM, and it is possible to show that this form of phase shift keying (PSK) is equivalent to DSB. Typically, the FM systems required bandwidths several times those of the modulating signal.

Indications are that data security is a concern for this system. For igital transmission systems, data security is relatively straightforward hrough the use of techniques such as the data encryption standard (DES). roviding security for wideband analog waveforms is of greater concern. echniques such as spread spectrum frequency hopping (SS-FH) could be nployed; however, there are questions regarding both the impact on required ignal bandwidth and on licensing of such systems. EES recommends that dditional consideration be given to the security factor before system nplementation begins.

Appendix A

LICENSING OF A STATION IN THE INDUSTRIAL MICROWAVE SERVICE

1. Interference Analysis (See SS94.15b)

The actual licensing process begins with an engineering analysis of the potential for interference between the service being proposed and any existing or pending radio services. The applicant must demonstrate that the proposed service will not produce harmful interference, as defined by FCC specifications, to other licensed services, or the applicant must reach an agreement with the affected parties that the interference level caused by the proposed service is acceptable to them even though it exceeds the maximum acceptable level defined by the FCC.

2. Application Filing (See SS94.15c, SS94.25c, SS94.27a, SS94.31b, SS94.31h, SS94.31i)

Application for a license in this service should be submitted on FCC Form 402 dated July 1976 at least 90 days prior to the desired date of approval, and the form should be submitted to the FCC's offices in Washington, D. C. In addition to the information requested on the form, the application should provide the following information:

- A system diagram
- Information on the construction, lighting, and marking of any associated towers
- The required environmental impact statement
- An indication of the basis for frequency selection
- An indication of the basis for bandwidth selection
- A schedule for implementation of the bandwidth utilization

. Station Construction (See SS94.27e, SS94.51)

Station construction must be completed within one year of the granting of he station license, and the licensee should notify the FCC of completion of onstruction, using Form 456.

. License Term and Fee (See SS94.39a, SS94.27f)

The term of a license in this service is five years, and the license may e renewed by submitting Form 405A to the FCC at least 90 days prior to the expiration of the current license. At present, there is no fee for a license in this service.

5. Verification Requirements (See SS94.82a, SS94.85b)

The operating characteristics of the station shall be determined by the licensee at least annually by measuring and recording the following parameters:

(1) Carrier frequency

(2) Transmitter output power

(3) Effective radiated power (ERP)

Deviations from the nominal values indicated on the station's license shall be promptly corrected.

6. Operation Requirements (See SS94.103a, SS94.103b, SS94.111a, SS94.113)

The routine operation of a station in this service may be performed by an unlicensed individual; however, the installation, testing, and servicing of a station must be done by an individual holding either a First Class or Second Class Radio Telephone or Radiotelegraph license.

Part of the routine operation of a station in this type is the verification that all tower lighting is functioning properly. This must be done at least every 24 hours.

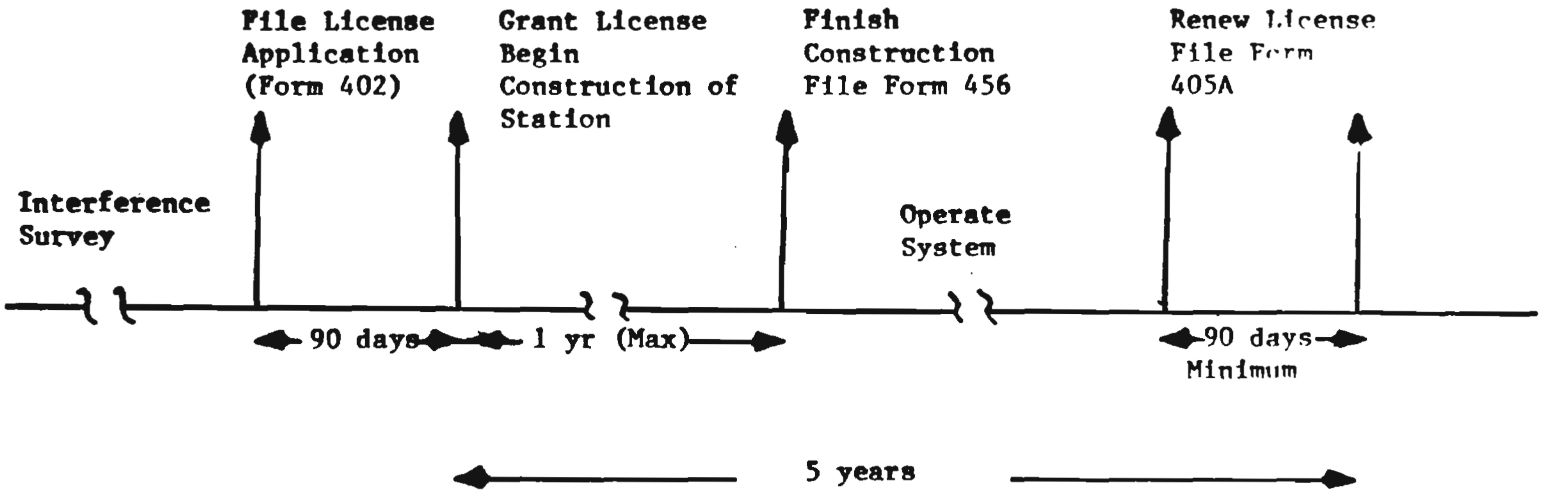
Another aspect of routine station operation is maintaining the station log. The log must record the following:

(1) The results of all required tests

(2) A description of all maintenance activities

(3) An entry indicating the time of the tower lighting observations

This log must be maintained for a period of one year after its last entry.



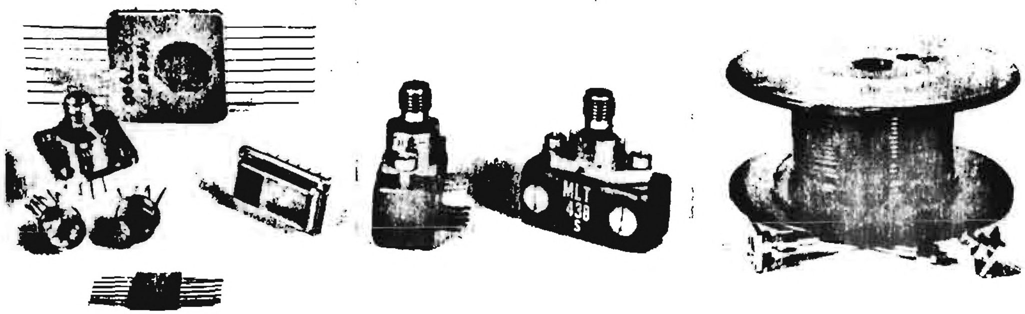
Timeline for Station Licensing

Appendix B

MERET

MODULES AND SYSTEMS

FOR OPTICAL COMMUNICATIONS



HYBRID TRANSMITTERS AND RECEIVERS

SUPERDIP TERMINALS

MODAL-SMA SYSTEMS

SHORT FORM CATALOG

HYBRID TRANSMITTER MODULES

High Speed IR-LED

Part No.	Peak Power (mW)	Rise Time (ns)	Frequency
ML25P*	0.5	2	DC–200 MHz
ML32	2.0	50	DC–8 MHz
ML33	1.5	12	DC–30 MHz
ML37	15.0	12	DC–30 MHz

*With ruggedized single fiber pigtail terminated

Integrated with TTL-drivers (TO-5)

Part No.	Peak Power (mW)	Rise Time (ns)	Frequency
MLT428	4.0	40	DC–15 Mbs
MLT438	3.0	10	DC–60 Mbs
MLT478	20.0	10	DC–60 Mbs

Integrated with SCR-drivers (DIP or flatpack)

Part No.	Peak Power (mW)	Rise Time (ns)	Frequency
FLP325	15.0	30	Up to 20 Kbs
FLP375	100.0	10	Up to 20 Kbs

Drivers Only (SCR-digital) for Injection Laser or LED Loads (Hybrids in DIP or flatpack)

Part No.	Peak Current (amps)	Rise Time (ns)	Frequency
FX41	100	50	Up to 0.5 Kbs
FX45	30	10	Up to 20.0 Kbs

Drivers Only (Analog) for CW Laser or LED Loads (Hybrids in DIP or flatpack)

Part No.	Peak Current (amps)	Rise Time (ns)	Frequency
D-24001	0.5	5	DC–70 MHz
D-24002	0.5	30	DC–10 MHz

ML & MLT Series

MA Series

DV, DK Series

Figure 2.

TRANSIMPEDANCE AMPLIFIERS, SINGLE SUPPLY OPERATION

Part No.	Trans-impedance (k Ω)	Bandwidth (MHz)	RMS Noise Volts (μV)
MA41	100	DC–1	100
MA7705	22	DC–10	90
MA7708	7	DC–40	80
MA7710	2	DC–100	70
MG7712	1	DC–160	100
DV45	400	0.1–5	2000
DK48	80	0.1–20	1000

PHOTODIODES

Low leakage, high speed isolated PIN photodiodes (TO-5)

Part No.	Responsivity at 905 nm (μA/μW)	Rise Time (ns)	Active Area (mm^2)
MD31	0.65	3	0.8
MD32 (Rect.)	0.65	5	4.5
MD33 (Circ.)	0.65	5	5.0
MD34	30.0	1	0.8

HYBRID DIGITAL RECEIVERS

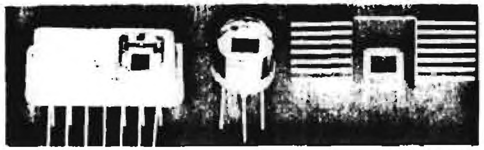
PIN photodiodes, transimpedance amplifiers, voltage comparators, and TTL-gates integrated into TO-5 cans

Part No.	P_{min} (μW)	Bit Rate (Mbs)
R1001	0.5	DC–0.50
R1101	2	DC–2
R1201	4	DC–4

P_{min} = Threshold power at 905 nm.
The bit-error rate at P_{min} is less than 10^{-12}.

HYBRID ANALOG RECEIVERS

Part No.	Responsivity at 905 nm (mV/μW)	Bandwidth (MHz)	RMS Noise Volts (μV)
PIN photodiode with transimpedance amplifiers. Single supply operation			
MDA431	50	DC–1.0	120
MDA435	10	DC–5	100
MDA438	3	DC–15	90
High speed, ultra-fast receivers, dual supply in TO-5 cans			
MDA7705	12	DC–11	100
MDA7708	4	DC–40	90
MDA7710	1	DC–100	75
PIN photodiode with transimpedance amplifiers and video amplifiers in DIP's			
DDV325	200	0.1–5	2000
DDK528P	40	0.1–20	1000
Large area (1 cm^2) photodiodes, transimpedance and video amplifiers in flatpack			
R7500	10	DC–5	100
R7550	200	0.1–5	2000
R7880	40	0.1–20	2000
R7900	1	DC–70	100
Multi-element receivers, 2 and 4 channels – duodiodes with balanced amplifiers in small flatpack			
F2DA425	6	DC–5	100
F2DA528	2	DC–20	90



DDV, DDK

Figure 3.

"MODAL" TRANSMITTER/RECEIVER SETS

(terminals in SMA, SUPERDIP, or minibox format; optical receptacles compatible with terminations on fiber optic cables — see Figs. 1 and 4)

Designation	Basic Xmtr	Basic Rcvr	Operating Freq. Range
MDL100 Series; Elemental System (LED/Photodiode) in SMA Format			
MDL124	ML32	MD33	DC–10 MHz
MDL139	ML33	MD33	DC–50 MHz
MDL151	ML25P	MD31	DC–150 MHz
MDL154	ML25P	MD34	DC–220 MHz
MDL200 Series; Analog Data Systems in Minibox Format (Transmitter in P3; Receiver in P1*)			
MDL221	20003	MDA531	DC–2 MHz
MDL235	20001	MDA7705	DC–10 MHz
MDL238	20001	MDA7708	DC–50 MHz
MDL258	20024	MDG7712	1 –150 MHz
*Receivers in SMA format are available			
MDL200-TV Series; Analog Systems for Transmission of Composite Video, 1V peak-to-peak, in-out			
MDL225-TV	20002	15001	20 Hz–6 MHz
MDL236-TV	20022	15059	20 Hz–20 MHz
MDL2255-TV*	20018*	15058*	20 Hz–6 MHz
MDL2365-TV*	20025*	15061*	20 Hz–20 MHz
*Operates from 117 volt line voltage			
MDL300 Series; "Common Denominator" Systems (LED Transmitter/Analog Receiver) in SMA Format			
MDL321	ML32	MDA431	DC–2 MHz
MDL338	ML33	MDA7708	DC–50 MHz
MDL358	ML25P	MDG7712	DC–150 MHz
MDL400 Series; Complete Digital Systems (TTL In/Out) Transmitter and Receiver in Minibox Format (P1*, P3, or P4)			
MDL421	MLT428 (P1)	15049 (P1)	DC–2 Mbs
MDL435	MLT438 (P1)	15056 (P3)	DC–10 Mbs
MDL437	MLT438 (P1)	15038 (P3)	DC–30 Mbs
MDL438	MLT438 (P1)	15054 (P3)	DC–60 Mbs
Digital Systems with Second Stages and Gain Equalization			
MDL4211*	MLT428 (P1)	15045 (P3)	DC–2 Mbs
MDL4377	MLT438 (P1)	15033 (P4)	DC–30 Mbs

*Transmitters in SMA format are available

FIBER CABLE, TERMINATIONS, AND ACCESSORIES

Cable Type	Approx No. of Fibers	Active Diameter Microns	Active Diameter Mils	Attenuation at 905 nm (dB/meter)	Coupling Loss (dB)
A	200	1100	45	0.7	6
B	37	580	24	0.1	10
C	200	1100	45	0.5	6
D	19	430	17	0.1	12
SC	1	75	3	0.01	23
SD	1	200	8	0.1	16

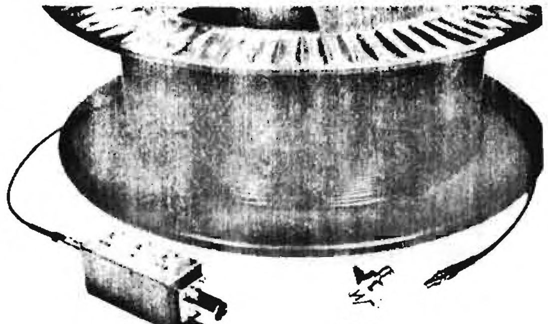
Types A, B, C, D are PVC-jacketed; SC and SD are ruggedized. Types CR and DR are ruggedized versions of Types C and D, respectively.

CABLE ACCESSORIES

Part No.	Description
97002	Receptacles for hybrid transmitter or receiver modules (TO-5) matched to SMA optical connectors
97003	SMA termination assembly including ferrule, ring, and nut for Types A & C cable
97004	SMA cable-to-cable connector
97024	SMA termination assembly including ferrule, ring, and nut for Type SD cable (25 mil hole)
97026	SMA termination assembly including ferrule, ring, and nut for Type SC cable (6-1/2 mil hole)

SYSTEM DESIGNATION AND ORDERING INFORMATION

A complete **MODAL** system is identified by combining the part number of the transmitter/receiver terminal pair (listed on page 3) with cable type and length. For example, to obtain a system operating from DC to 2 Mbs over 30 meters of Type C cable, you would order the MDL421–C30. If either the compact SMA or SUPERDIP format is desired, the system identification would be MDL421(SMA)—C30 or MDL421(SDP)—C30, respectively.



MINIBOX (P3) SMA

Figure 4.

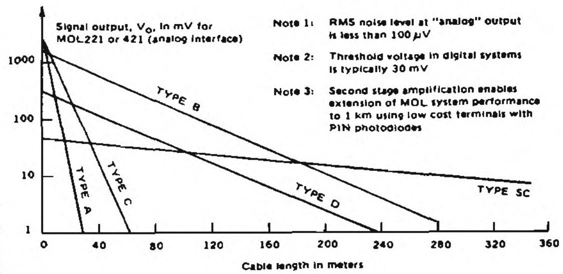


Figure 5. Signal Output as a Function of Cable Length for Typical MODAL Systems

MERET INC. Manufacturers of Hybrid Opto-Electronics
1815 - 24th Street, Santa Monica, Ca. 90404 • (213) 828-7496 • TELEX: 65-2468 SNM

MERET INC.
Manufactures of Hybrid Opto-Electronics
1815 - 24th Street, Santa Monica, Ca. 90404 • (213) 828-7496 • TELEX: 65-2468 SNM

MERET QUOTATION

Georgia Tech
Engineering Experimental Station
347 Ferst Dr. NW
Atlanta, GA 30332

Attn: Pat Elam

DATE: Aug. 10, 1979

MQP NO: 791806

DELIVERY: Items 1,3: 6 weeks
2,4: 10 weeks

RESPONSE TO: telecon inquiry of 8/10/79

NO.	DESCRIPTION	QUAN.	UNIT PRICE	AMOUNT
12-0	Complete duplex system for transmission of digital data through the atmosphere from DC to 5 Mbps per specifications attached	5-9	$3,980-	
		10-24	$2,920-	
13-0	Same as Item 1, per specs attached	5-9	$7,800-	
		10-24	$6,550-	
22-00	Same as Item 1, per specs attached	5-9	$3,650-	
		10-24	$2,640-	
23-00	Same as Item 1, per specs attached	5-9	$7,350-	
		10-24	$6,200-	

ION ON PRICE AND DELIVERY IS
PERIOD OF 60 DAYS FROM THE
UNLESS OTHERWISE SPECIFIED.

APPROVED: [signature]

MERET INC.

Manufacturers of Hybrid Opto-Electronics

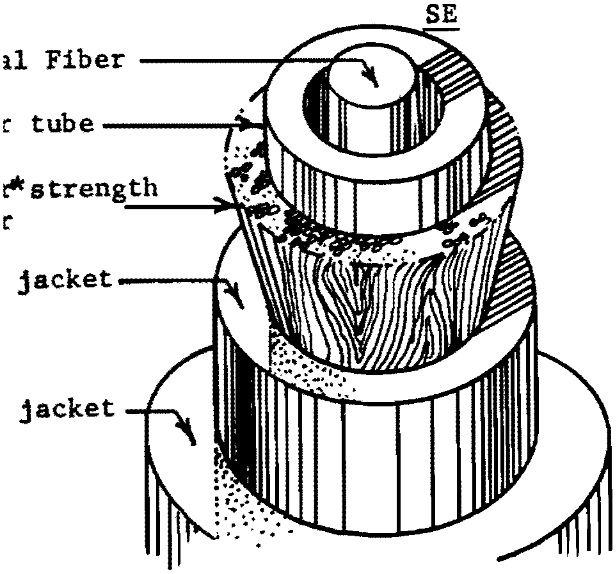
1815 - 24th Street, Santa Monica, Ca. 90404 • (213) 828-7496 • TELEX: 65-2468 SNM

SPECIFICATIONS OF RUGGEDIZED SINGLE FIBER SIMPLEX CABLES

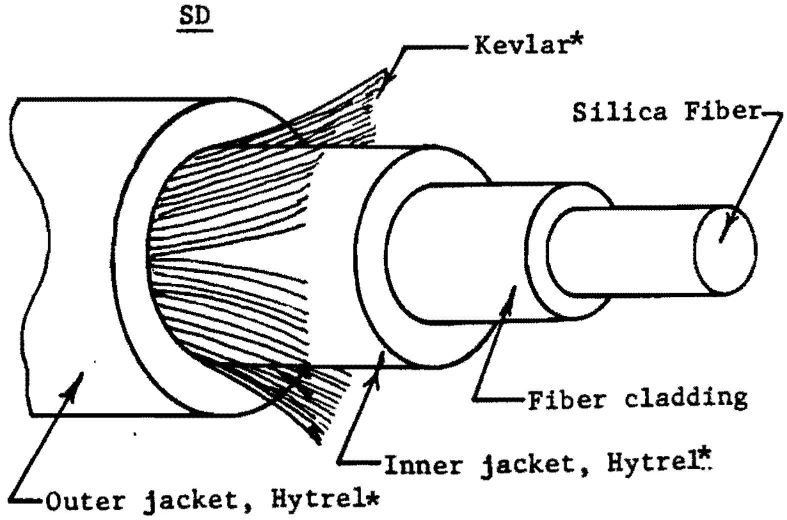
Duplex cables containing two individually buffered fibers within the same common jacket are also available)

	SC	SG	SD	SE	UNITS
of fibers	1	1	1	1	----
ex profile	graded	step	step	step	----
e diameter	62.5 or 75	300	200	250	microns
er diameter	125	440	600	300	microns
erical Aperture	0.21	0.22	0.4	0.35	----
enuation @					
300 nm	8	10	60	15	dB/km
900 nm	15	20	100	30	dB/km
er Diameter	4	4	2.4	5	mm
imum Bending Radius	50	50	3.0	40	mm
sile Strength	80	80	30	80	kg
dwidth (1 km)	200	20	50	20	MHz
ght	14	13.5	6	13	gm/meter
rule Part No.	97026	97025	97024	97029	----

SE



SD



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MERET INC.

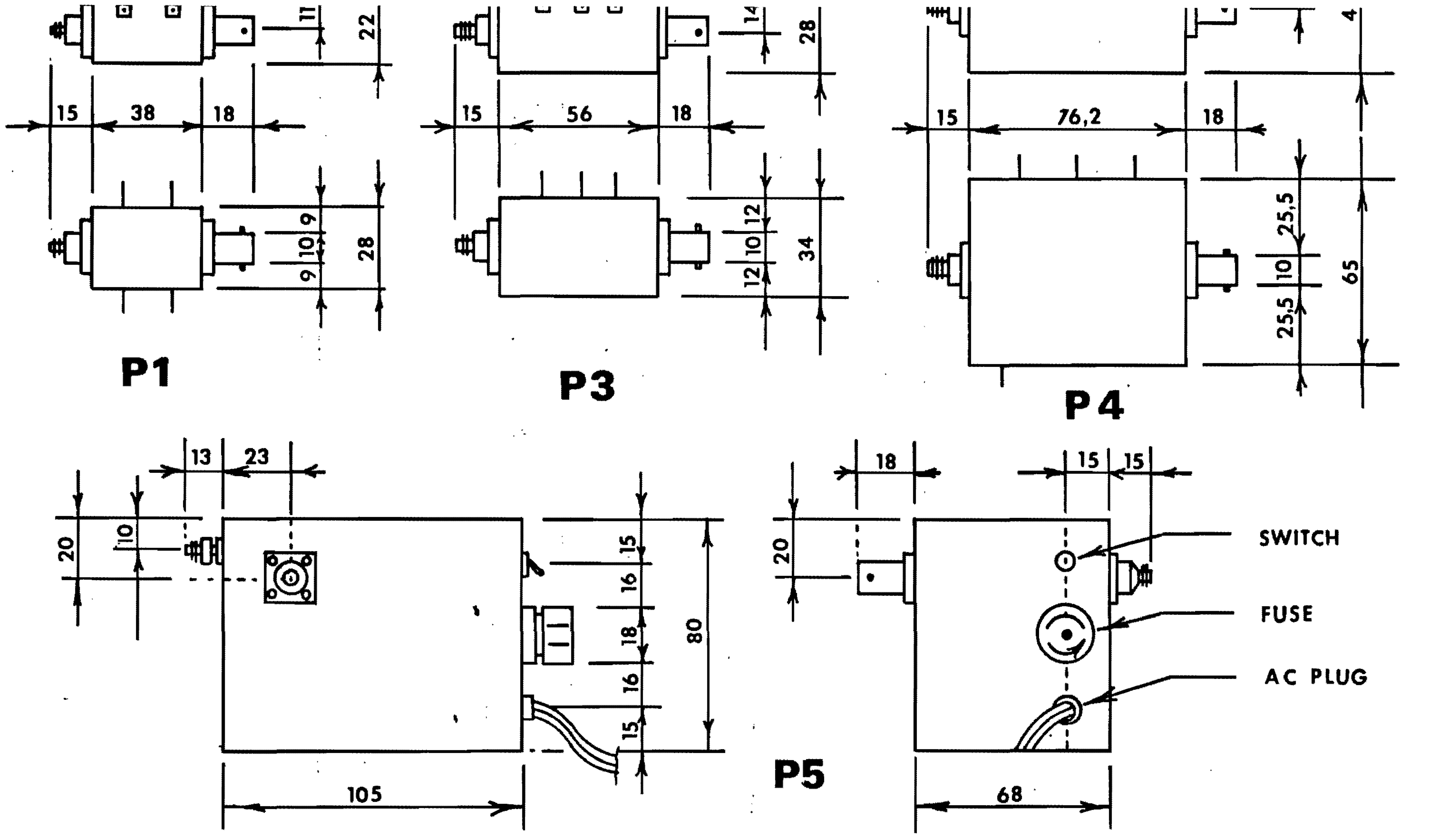
Manufacturers of Hybrid Opto-Elect

1815 - 24th Street, Santa Monica, Ca. 90404 • (213) 828-7496 • TELEX: 65-24

Specifications on Multifiber Optical Cables for Types A,C,D, and Types CR and DR, Heavy Duty Ruggedized Cables

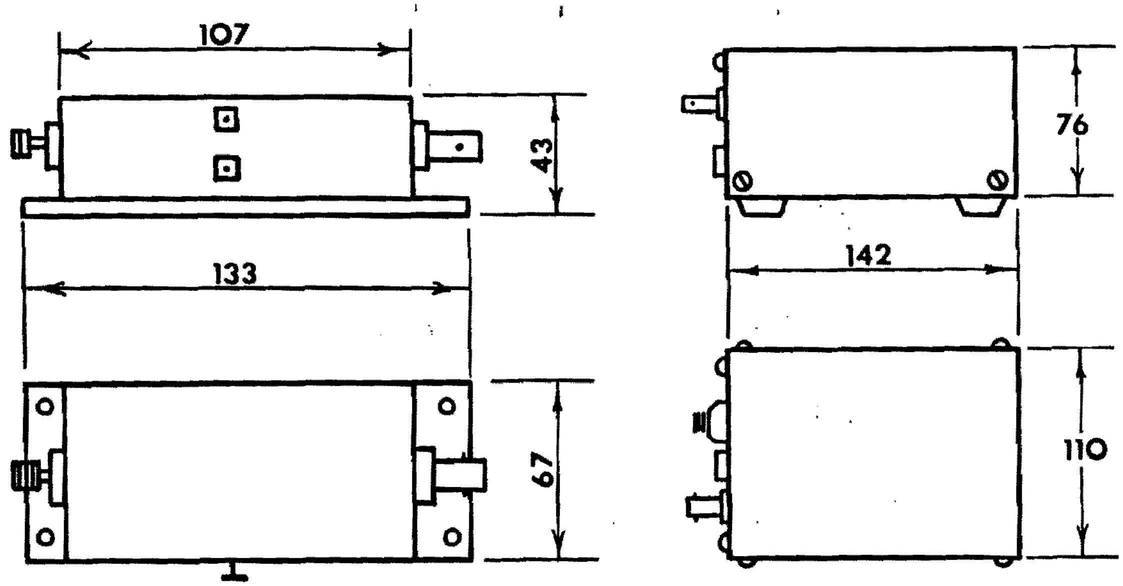
PARAMETER	TYPES A,C	D	CR	DR	UNITS
No. of fibers, approx.	200	19	200	19	----
Individual fiber diam.	68	85	68	85	microns
Core diameter	62	68	62	68	microns
Bundle diameter	1.2	0.43	1.2	0.43	mm
Numerical aperture	0.66	0.48	0.66	0.48	----
Estimated Insertion loss (ML33 transmitter in SMA receptacle)	6	13	6	13	dB
Optical attenuation at 800 to 900 nm	750,850	< 60	550	80	dB/KM
Jacket Material	PVC	PVC	Kevlar & Teflon	Kevlar & Teflon	----
Useable temp. range	-10 to +105	-10 to +105	-55 to +150	-55 to +150	^{o}C
Weight	6	2	18	14	gm/met
Minimum bend radius	6.3	6.3	19	19	mm
Outside diameter	2.34	1.42	3.81	3.81	mm
Maximum Recommended Tensile Loads	2	2	50	50	Kg
Ferrule Part No.	97003	97025	97011	97012	----

Note: Standard lengths of Types A,C are available at 1,3,6,9,10,15,20 and 30 mete



NOTE: ALL DIMENSIONS ARE IN MILLIMETERS; NUMBER OF PINS & LOCATION MAY VARY W/PART NR.

TITLE MINIBOXES FOR M.O.D.A.L. SYSTEMS		DRAWN BY M.NICOLAIDE	REVISION. NO.
SCALE 1/2	DATE 8-31-1978	MWO	REPLACES DWG. NO.
MERET Inc. 1815 - 24th Street, Santa Monica, Calif. 90404		TOLERANCES — UNLESS OTHERWISE SPECIFIED — DECIMALS: .005 FRACTIONS: 1/64 ANGLES: 10	DWG. NO. MB78701



P6　　**P7**

NOTE: ALL DIMENSIONS ARE IN MILLIMETERS ; NUMBER OF PINS & LOCATIONS MAY VARY WITH PART NUMBER.

TITLE MINI-BOXES FOR M.O.D.A.L. SYSTEMS		DRAWN BY M. NICOLAIDE	REVISION. NO.
SCALE	DATE 2-6-1979	MWO	REPLACES DWG. NO.
MERET Inc. 1815 - 24th Street, Santa Monica, Calif. 90404		TOLERANCES – UNLESS OTHERWISE SPECIFIED – DECIMALS: .005 FRACTIONS: 1/64 ANGLES: 1°	DWG. NO.

2/79 DM

MERET INC. Manufactures of Hybrid Opto-Electronics
1815 - 24th Street, Santa Monica, Ca. 90404 • (213) 828-7496 • TELEX: 65-2468 SNM

)L4300/4500 Series: Digital (TTL-Compatible) Optical Data Link for Transmission
' NRZ Data (from DC) to 50 Mbps over Medium-haul Cables (to 2 km)

ıtroduction

The MODAL systems designated as MDL4355 and 4377 are similar to MDL435 and 37 but the receivers contain an additional stage of amplification between the ·ont end and the comparator. As a consequence,these systems are useful for igh speed data transmission over cable lengths from 40 to 500 meters (see Fig.5 ' MERET Short Form Catalog). Special transmitters in P6 minibox are used for ›nger distances (to 3 km). Bit-error-rates are less than 10^{-10}.

·ansmitter

The standard transmitter for MDL4300 series is the MLT438 which combines 'L-driver circuits with a high speed IR-LED. Unless specified as OEM format, the ;andard package is the P1 minibox complete with BNC electrical input and power ıpply feedthroughs (+5 volts and ground). Current drain at 50% duty cycle is !0 mA maximum.

The IR-LED is "OFF" when voltages greater than +2.4 volts are applied to ıe input terminal and "ON" for signals between ground and +0.8 volts. (see ıveforms below).

As noted above, special high speed transmitters are available with good ıjection efficiency into graded index cable such as Type SC. These transmitters ›mbine the high speed drive circuitry with a pigtail edge-emitter IR-LED all ›ntained within the P6 minibox. These transmitters designated as MLT458 (P6) ·e used when the data rate-distance product exceeds 5 Mbps-km.

Thus, the MODAL system designated as MDL4377-SC1000 or MDL4377-SC500 requires ıe MLT458 transmitter.

:ceiver

The receivers for the MDL4300/4500 Series are comprised of an integral :tector-amplifier within SMA receptacle, a video amplifier and comparator circuit. |1 units are incorporated with suitable decoupling and gain equalization networks ithin the P3 minibox. Power requirements are listed as follows:

Voltage	Current
+12V	60 mA
-12V	20 mA
-30V	1 μA

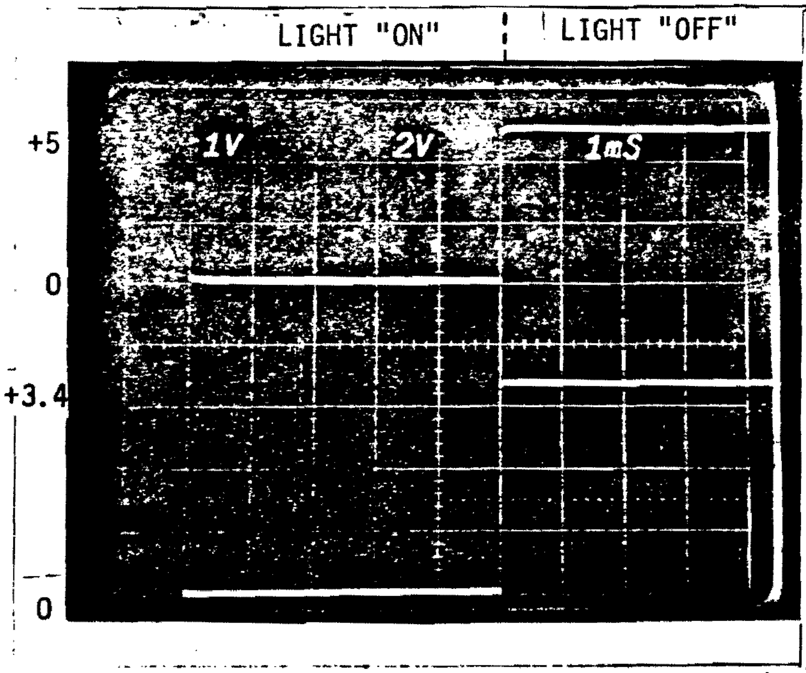
›te that the -30V supply pin which provides bias for the photodiode can be tied) the -12V pin and both operated from a single -12V supply with some increase in itter at the higher frequencies.

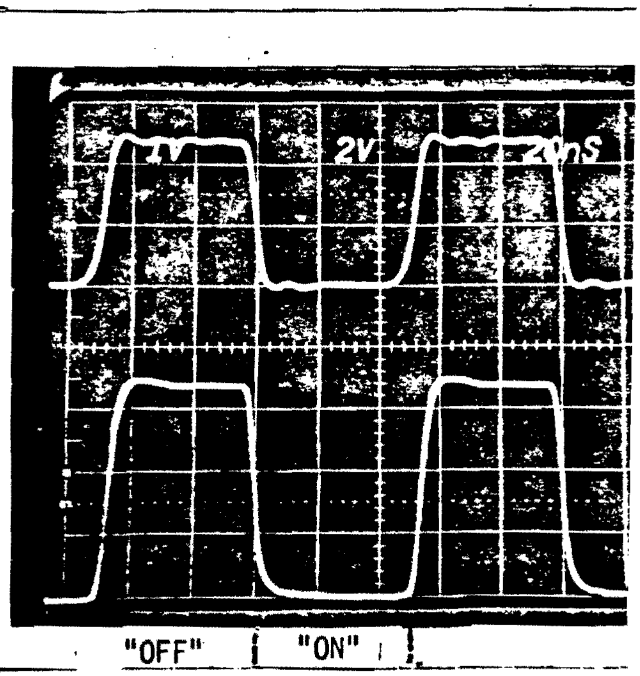
A test point for a high impedance probe can be used to sample the analog ıtput at the video amplifier as a link monitor. The optimum signal value at this ›int is in the range 75 to 100 mV. The video amp output is connected to the test ›int through a 10kΩ resistor in order to protect the circuit. This resistance ılue limits the rise times into capacitive loads such as scope probes. In order) properly monitor the output level one should use pulse widths on the order of one microsecond. Access to a variable gain agjust is provided so that the same receiver can be used over a wide dynamic range in optical power.

Typical System Specifications

PARAMETER	VALUE			UNITS
	MDL4355	MDL4377	MDL458	
Data rate , NRZ	10	25	50	Mbps
TTL - loads				
Input	2	2	2	-
Output	6	6	6	-
Max. cable length (Type SG) using MLT438 in P1 minibox	500	300	-	meters
Max. cable length (Type SC) using MLT458 in P6 minibox	3	2	1	km

Typical System Performance: MDL4577-SC1000
(MDL4577 is used to designate MDL4377 when MLT458 is the transmitter): One km of Type SC cable between transmitter and receiver





Response of data link to NRZ data corresponding to continuous string of 2.5 x 10^5 bits

Top Trace: Input at 2V/div.

Response of data link to high speed data at 20 Mbps, 50% duty cycle

Top Trace: Input at 2V/div.

Bottom Trace: Output at 1V/div.

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MODAL SYSTEMS FOR TRANSMISSION OF DIGITAL DATA, MDL400 SERIES

MDL420 are TTL-compatible fiber optic terminal systems (transmitter/receiver rs for operation with RZ or NRZ data to 5 Mbps. The system consists of a ies MLT400 IR-LED transmitter and a receiver combining an MDA (det/amp) and iparator in SMA or TPS receptacles, skinny dips, or minibox packages.

These systems are designed to trigger on "negative TTL input logic"; that is, transmitter is "on" at a ground ("0" level) input state, and is "off" at a h ("1" level) input state. The receiver output is non-inverting to the input te. With no light input, the receiver will give a "high" level output as long an initialization signal of at least two bits is provided after power-up.

Other standard terminal pairs in the MDL400 Series are MDL435 (to 10 Mbps), 437 (to 30 Mbps) and MDL458 (to 50 Mbps).

ECL-compatible systems to 100 Mbps are now available on a custom basis.

AMETER	VALUES MDL420	MDL421	MDL422	UNITS
. system bit rate (for jitter less than 10%)	0.2	2	5	Mbs
eiver characteristics:				
Analog responsivity @ 905 nm, typ.	> 360	> 60	> 20	mV/µW
Incident power required to trigger, min.	> 0.2	> 1	> 3	µW

COMMON RECEIVER CHARACTERISTICS

noise at analog output	< 100	µV
iparator threshold	< 40	mV
offset at analog output, typ.	+ 1.5	V
ital output rise, fall time	< 80	nsec
put drive	6	TTL loads
ic "1" output	> 2.5	V
ic "0" output	< 0.8	V
er Supply*	± 12	V
rent drain, max.	+40, -10	mA

COMMON TRANSMITTER CHARACTERISTICS

insmitter characteristics:		
Input load	2	TTL-loads
Power supply	+ 5	V
Current drain @ 50% duty cycle	100	mA

Receiver modules in SMA and OEM-dip format can be operated over a voltage range from ±5 V to ±15 V.

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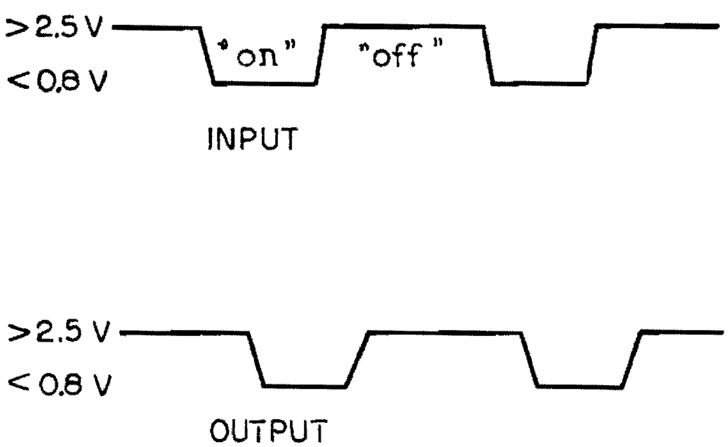
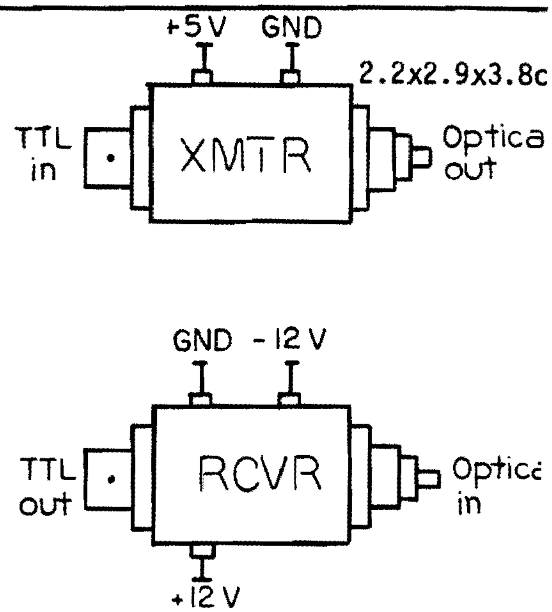
MDL 400 SERIES

VOLTAGE WAVEFORMS

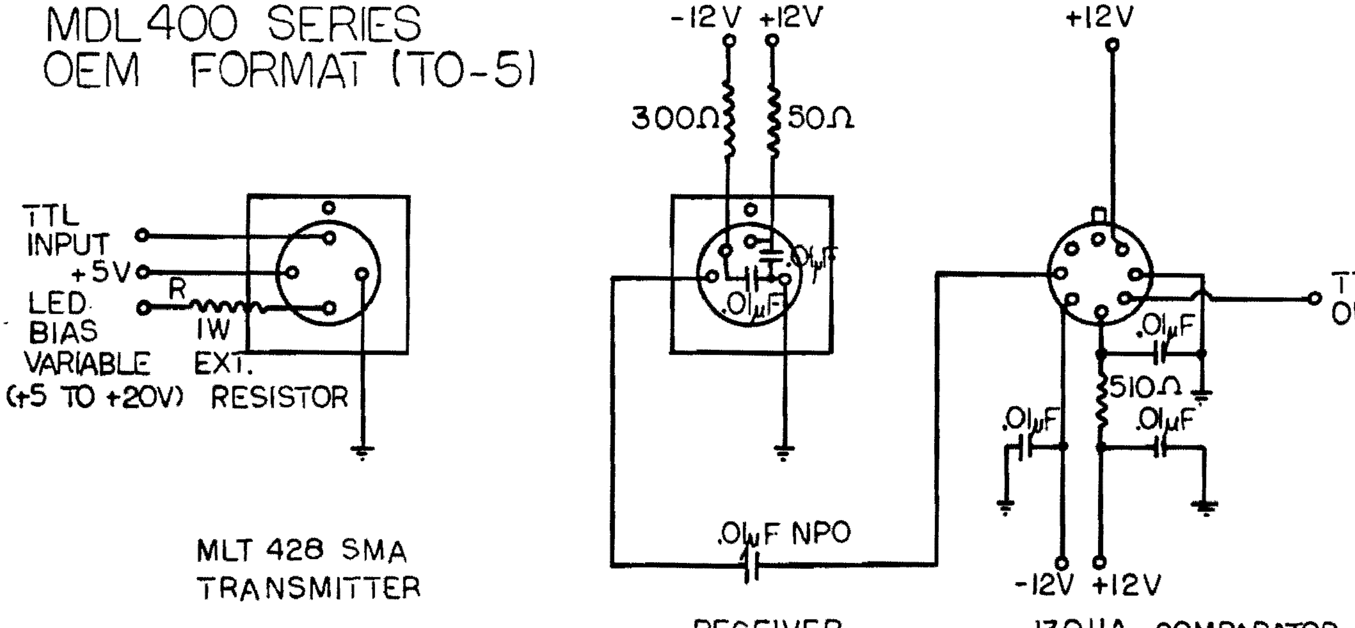


MINIBOX FORMAT



The compact miniboxes above which include all internal decoupling networks represent the standard MODAL Series 400 package for transmitter and receiver terminals. For direct panel integration under high density conditions or on closely spaced PC-board: the OEM format (SMA, TPS or Skinny Dip receptacles) is the preferred off-the-shelf, low-cost alternative.

MDL400 SERIES OEM FORMAT (TO-5)



MLT 428 SMA TRANSMITTER

RECEIVER FRONT END (MDB)

13011A COMPARATOR

	MDL 420	421	422
OEM RCVR. PN	MDB 510	MDB 511	MDB 512

eld-Proven Hardware That Gives You a .ow-Cost Short-Haul munications Alternative.

L OR ANALOG Whether you need to t studio-quality TV, or digital data from Mbps, one of our standard free-space ill meet your needs. Custom links with idths to 200 MHz or with digital data) 100 Mbps are also available. You have ıoice of ac-line or low-voltage-dc oper- ɔr transmitter and receiver.

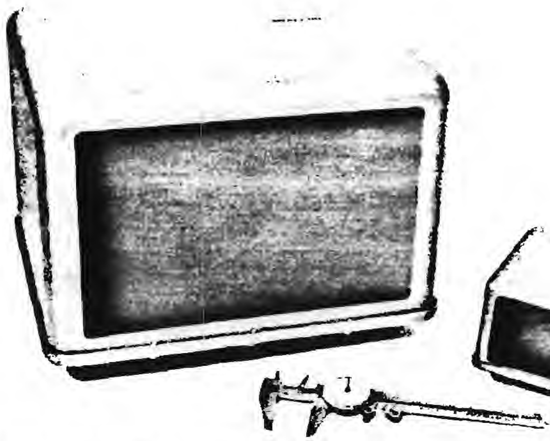
MDL600 Series are simplex links for ısmission of analog data or composite

MDL800 Series are digital links which ə configured in either the simplex or mode. When operated as a duplex link, ɔarate receiver and transmitter modules 'esighted together, after being mounted ɔmmon frame.

h the composite video and digital series ıt-emitting diodes in the transmitter ter- ınd PIN photodiodes in the receiver ter- Large-aperture receivers are used in ction with the highest-power transmit- the most demanding applications.

:RMITS No special license is required ɜration at your site. Because all MERET links use eye-safe infrared LEDs in the itter, neither the Federal Communications ission nor the Bureau of Radiological ı places any restrictions on operation. ɔortant consideration in crowded urban nments.

/IMUNITY AND SECURITY The immu- the optical carrier to electromagnetic rence makes these links ideal for a vari- situations where electrical cable or vave is not practical. Links have been uccessfully in electrically noisy environ- such as power stations, reactors, refin- and automated warehouses, and for ıission of secure data.



QUICK INSTALLATION Small size and light weight make the link easy to set up, whether for permanent or temporary installations. You need only a stable platform for mounting, such as an inside or outside wall, a free-standing mast or heavy-duty tripod.

NO WIRES OR CABLES No wires, cables, ducts or conduits of any kind are required. That means it's easy to get across rivers, railroad rights-of-way, streets, or from building to building.

COMMUNICATIONS RANGE The range you can achieve depends upon data rate, platform stability and atmospheric attenuation.

Unstable platforms require that the transmitter beam divergence be adjusted to a relatively wide angle in order that the receiver will always intercept the transmitter beam. The consequent reduction in power density at the receiver limits the range you can achieve with a satisfactory fade margin.

If you plan to operate the link indoors, you will not have to be concerned with atmospheric attenuation.

If, however, you want to operate outside, weather is a consideration. Fog, dust and blowing sand are the worst enemies of reliable communications. So if you need an "all-weather" link, the platform must be quite stable, and the range is usually limited to less than one kilometer, even for low data rates.

In the specification section you'll find information on expected ranges with different transmitter beamwidths.

SPECIFICATIONS

Series MDL600 TV Link

ction.... weather-tight aluminum housing
dth...... 5 Hz to 5 MHz, 3 dB points
mat.....analog, 1 mv to 1 v, p-p
tor type
l........ BNC
r........ Amphenol 126-1085 standard, others available.
l power,
ter
rsions ... 117 v, 50/60 Hz, 0.25 A
rsions ... −15 vdc, 0.25 A
l power,
r
rsions ... 117 v, 50/60 Hz, 0.25 A
rsions ... ±15 vdc, 0.1 A

ations by Model Number

S/N of 40dB, for good weather or indoor path.

ansmitter ED Power	Transmitter Chassis	Receiver Chassis	Receiver Aperture	External Power	Transmitter Beam Divergence	Range
2mW	B	B	45cm²	ac line	10mrad 5mrad	50m 100m
20mW	B	B	45cm²	ac line	30mrad 10mrad 5mrad	50m 150m 300m
20mW	B	C	450cm²	ac line	30mrad 10mrad 5mrad	200m 500m 1000m
2mW	A	A	45cm²	low voltage dc	10mrad 5mrad	50m 100m
20mW	A	A	45cm²	low voltage dc	30mrad 10mrad 5mrad	50m 150m 300m
20mW	A	C	450cm²	low voltage dc	30mrad 10mrad 5mrad	200m 500m 1000m

Series MDL800 Digital Link

Construction.... weather-tight aluminum housing
Data rate....... dc to 5 Mbps
Data format..... TTL
Connector type,
Signal and
power........ Amphenol 126-1085 standard, others available.
External power,
transmitter
ac versions ... 117 v, 50/60 Hz, 0.25 A
dc versions ... +5 vdc, 0.25 A
External power,
receiver
ac versions ... 117 v, 50/60 Hz, 0.25 A
dc versions ... ±15 vdc, 0.1 A

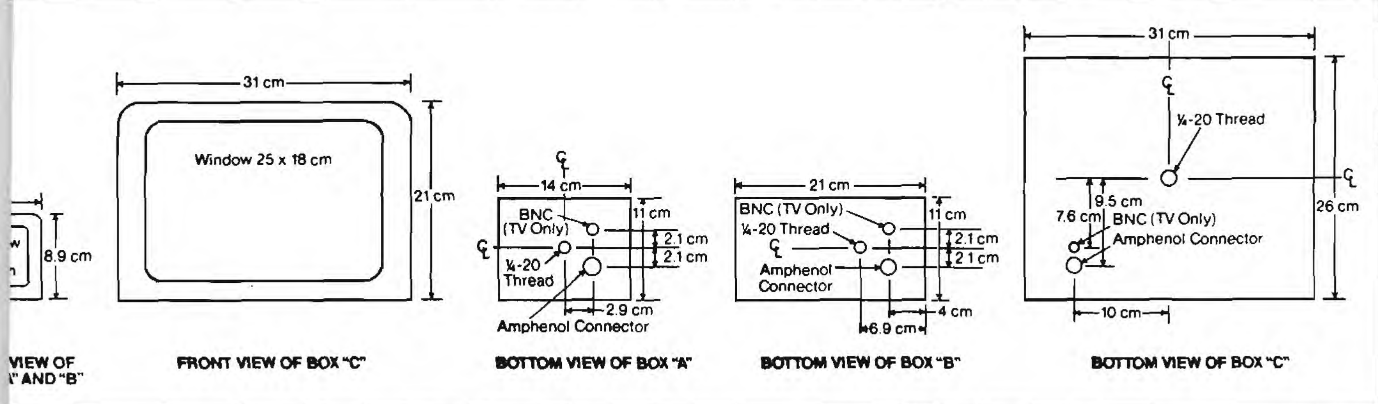
Specifications by Model Number

Range with bit-error-rate of less than 10^{-10} for good weather or indoor path.

Model	Transmitter LED Power	Transmitter Chassis	Receiver Chassis	Receiver Aperture	External Power	Transmitter Beam Divergence	Range
MDL811	2mW	B	B	45cm²	ac line	10mrad 5mrad	50m 100m
MDL812	20mW	B	B	45cm²	ac line	20mrad 10mrad 5mrad	50m 100m 200m
MDL813	20mW	B	C	450cm²	ac line	30mrad 10mrad 5mrad	200m 500m 1000m
MDL821	2mW	A	A	45cm²	low voltage dc	10mrad 5mrad	50m 100m
MDL822	20mW	A	A	45cm²	low voltage dc	20mrad 10mrad 5mrad	50m 100m 200m
MDL823	20mW	A	C	450cm²	low voltage dc	30mrad 10mrad 5mrad	200m 500m 1000m

HOW TO ORDER

lete system designation combines the basic model number with the range in meters. For example, nal set designed for transmission of composite video over one kilometer and operated from low dc would be designated MDL623-1000.



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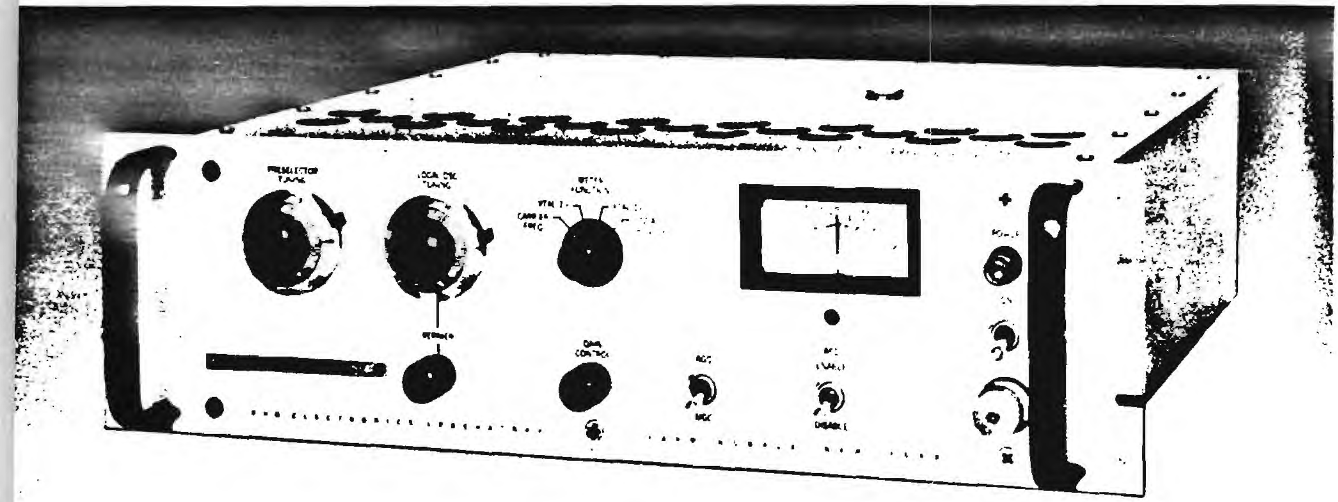
RHG

MICROWAVE FM RECEIVERS

■ Video Data Links ■ Digital Transmission ■ Basebands to 12 MHz



HG has been heavily involved in wide-band FM de-odulation systems since 1961. The receivers listed elow reflect those models which are most often required or TV and digital transmissions.

The design and construction reflects field proven chniques to assure maximum fidelity and high reliability.

If your requirements are not satisfied by the listed models, it is very probable that our design files may include your exact needs. If not, a custom design tailored to specific needs can usually be offered with nominal nonrecurring charges.

IDE-BAND MODELS (6 MHz baseband)

Model Number	Tuning	Available in band of	Price
FMR1.7	Fixed	1.7 to 1.85	$7400
FMR2.2	Fixed	2.2 to 2.3	7400
FMR3.7	Fixed	3.7 to 4.2	7750
FMR4.4	Fixed	4.4 to 5.0	7950
FMR6.8	Fixed	6.8 to 7.2	7950
FMR7.1	Fixed	7.1 to 8.4	7950
FMR12.2	Fixed	12.2 to 13.25	8400

VERY WIDE-BAND MODELS (12 MHz baseband)

Model Number	Tuning	Available in band of	Price
FMRW1.7	Fixed	1.7 to 1.85	$8400
FMRW2.2	Fixed	2.2 to 2.3	8400
FMRW3.7	Fixed	3.7 to 4.2	8750
FMRW4.4	Fixed	4.4 to 5.0	8995
FMRW6.8	Fixed	6.8 to 7.2	8995
FMRW7.1	Fixed	7.1 to 8.4	8995
FMRW12.2	Fixed	12.2 to 13.25	9400

DDITIONAL SPECIFICATIONS

- Noise Figure: 9 dB typical on all units plus preselector loss if used.
- RF Isolator: Standard on all units.
- AGC/MGC: Front panel switch selectable with 50 dB (typical) range.
- Monitor: Front panel monitoring of signal strength and relative carrier frequency.
- Video Baseband: ± 0.5 dB over 10 Hz to 6 MHz on wide-band models and ± 1.0 dB, 10 Hz to 12 MHz on very wide-band models.
- IF Bandwidth: 30 MHz on wide-band models; 50 MHz on very wide-band models.
- Video Outputs: Two suppliedat 75 Ω impedance level.
- Video Sensitivity: 1.0 p-p for ± 4 MHz deviation.

OPTIONS:

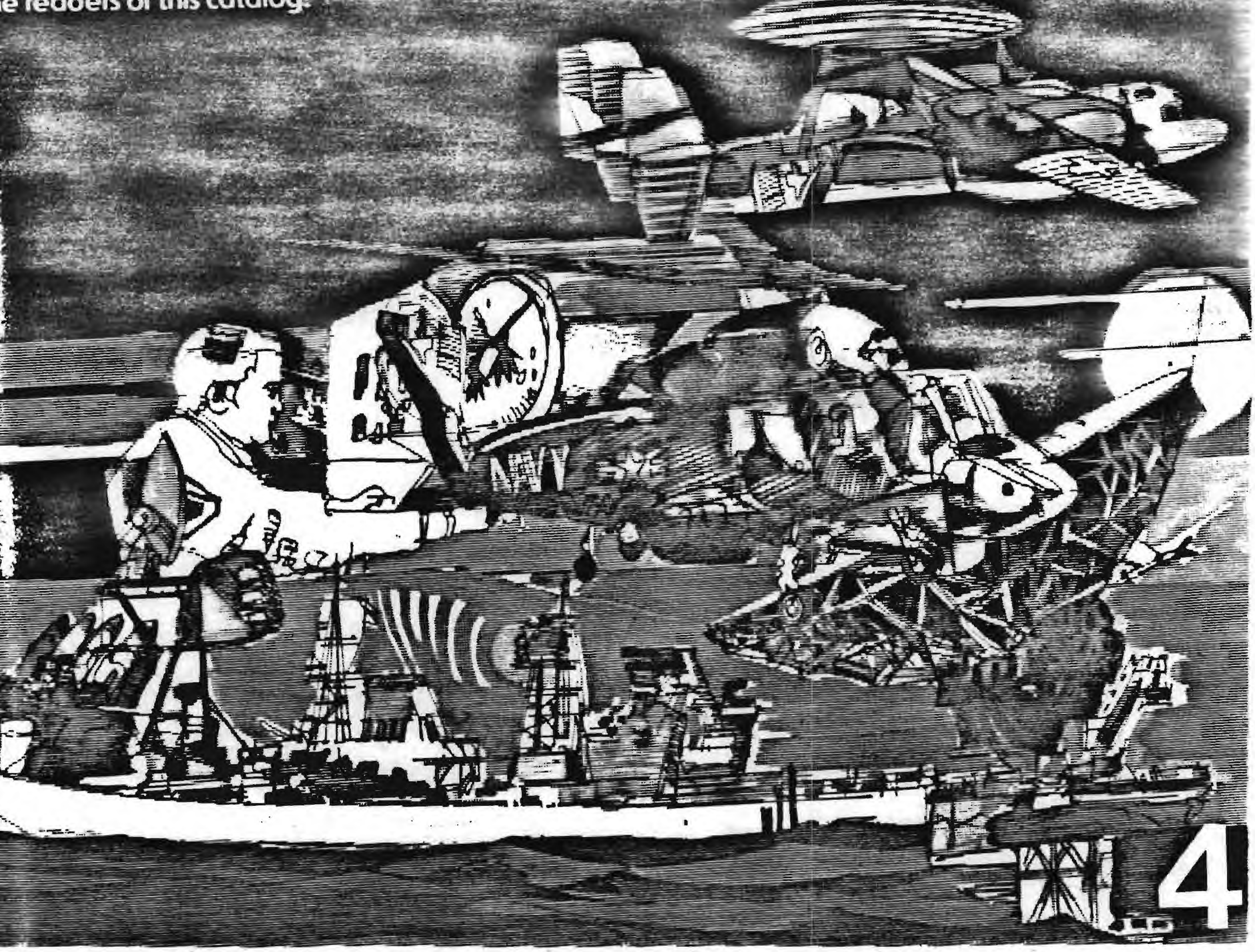
1. RF Preselector (fixed freq.): Add suffix "P"—$500 additional.
2. AFC (not applicable to 12.2 GHz models which are crystal controlled): Add suffix "F"—$450 additional.
3. AM Tracking Output: Add suffix "T"—$50 additional.
4. De-emphasis (std 525 line CCIR): Add suffix "D"—$200 additional.
5. Audio Subcarrier Demod (7.5 MHz): Add suffix "S"—$800 additional. NOTE: Not for FMRW series.
6. Front panel frequency tuning and tuneable preselectors available—contact factory.
7. PM demodulator models available—contact factory.
8. ATR airborne packaging available—contact factory.

How to Specify: Place option suffixes in alphabetical order, following model number.

RHG RHG ELECTRONICS LABORATORY·INC

Vorldwide-The SOURCE for...
Technical Information on
Microwave & IF/RF Products.

e members of RHG's technical
aff have contributed a number
articles for publication in
urnals serving the engineering
ommunity. The following section
cludes a selection of these
apers that will be of interest to
e readers of this catalog.



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GTE Lenkurt makes available three basic types of microwave radio transmission systems, IF heterodyne (type 75), baseband (type 70F1 and type 78), and RF (type 700F1). The heterodyne system offers greater capacity and performance over longer transmission routes than the other systems. For short and medium distance routes, and for networks requiring a considerable amount of dropping and insertion of VF channels at intermediate repeaters, the baseband system is generally favored. The RF repeater system is utilized as an intermediate link between 70F1 radio terminals and provides no drop or insert capability. In many instances, however, a microwave network can take advantage of the best features of all types of radios at the lowest possible cost.

Radio products are grouped by class corresponding to type of service (common carrier, industrial or government). As an example, a 778A3 transmitter-receiver plus an assortment of other subsystems (see page 10) operates in the 6-GHz common carrier frequency band.

The block diagram at the right illustrates how the type 75 and the type 78 radio systems are completed with the use of various subsystems. The type 70F1 radio system includes baseband equipment as part of the basic package. Only the type 51F Alarm System and the type 53C Order Wire may be added to enhance its operational capability.

Type No: 70F1 Microwave Radio System — Baseband
No. of Channels: 36
Frequency Range: 2110-2200 MHz
Transmitter Power Output: 30 dBm
General Descriptive Publication: Form GTEP 394-706-110

The 70F1 is a very compact and economical microwave radio system operating in the 2110 MHz to 2200 MHz industrial and common carrier frequency allocations. With a capacity of up to 36 VF channels and RF spacing of as close as 1.6 MHz, the 70F1 is well suited for light-route backbone or spur route applications. Single channel and hot-standby arrangements are available.

Type No: 700F1 RF Repeater
No. of Channels: 36
Frequency Range: 2110-2200 MHz
System Gain: 45 dB (min.)
General Descriptive Publication: Form GTEP 394-706-115

The 700F1 is a self-contained RF repeater licensed for use as an intermediate microwave radio link for the GTE Lenkurt type 70F1 2-GHz Microwave Radio System. A unique concept in microwave repeaters, the 700F1 filters and amplifies the signals passing through it without shifting or changing the frequency. Capable of being completely self-powered with solar energy, the 700F1 provides an extremely low-cost alternative to high-priced active baseband or passive "billboard" repeaters for communications service in the 2-GHz frequency band.

75 Microwave Radio Systems — Heterodyne

Xmtr Type Designation	No. of Channels	Frequency Range	Transmitter Power Output
775A3	2100 or TV	5925-6425 MHz	37.5 dBm
775B3	2100 or TV	6425-7125 MHz	37.5 dBm
775C1	1200 or TV	7125-8400 MHz	40 dBm
775D1	1800 or TV	10,700-11,700 MHz	40 dBm
775D1	1200 or TV	12,200-13,250 MHz	37 dBm
775G2	1500 or TV	3700-4200 MHz	40 dBm

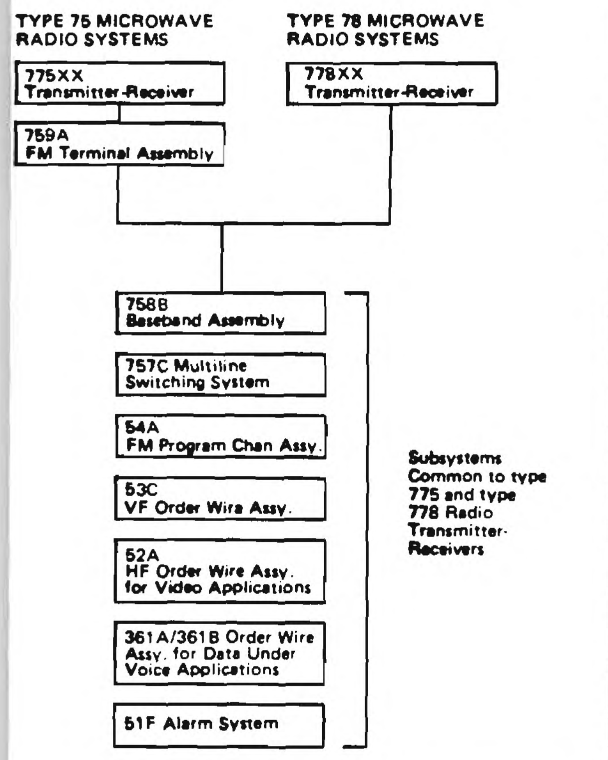
General Descriptive Publication: Form GTEP 394-750-100, Form GTEP 394-751-100 (775A3/B3)

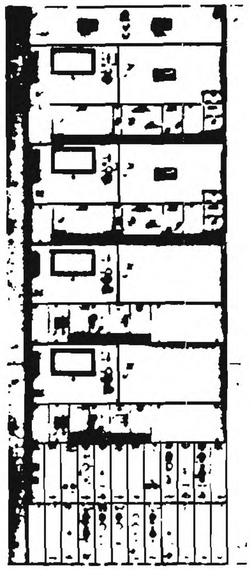
Type 75 radios form a complete family of long-haul, high-performance IF heterodyne microwave systems. These advanced systems are particularly suited for new routes, for expansion of existing high-message-capacity backbone routes of 2,000 miles or more, and also for networks carrying large volumes of data traffic. Hot-standby, space-diversity, frequency-diversity, multiline switching, and single-channel unprotected arrangements are available. Overall performance of the 75 systems meets CCIR and Bell System transcontinental specifications for message transmission, CCIR Trans Canada, and NTSC requirements for both black-and-white and color television.

78 Microwave Radio Systems — Baseband

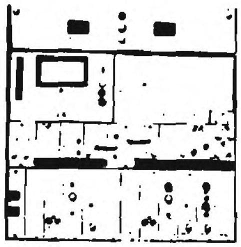
Xmtr Type Designation	No. of Channels	Frequency Range	Transmitter Power Output
778A3	1800 or TV	5925-6425 MHz	30 dBm
778B3	1200 or TV	6425-7125 MHz	30 dBm
778C3	1200 or TV	7125-8400 MHz	30 dBm
778D3	1800 or TV	10,700-11,700 MHz	25 dBm, Min
778E3	1200 or TV	12,200-13,250 MHz	25 dBm, Min
778F2A	*600 or TV	1700-2300 MHz	37 dBm

General Descriptive Publication: GTEP 394-780-100

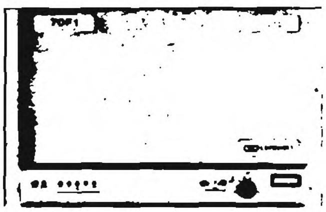




Type 778A1 Hot-Standby Space-Diversity Assy.

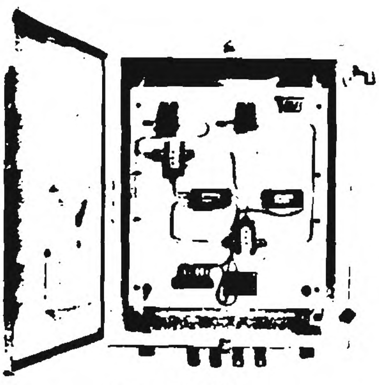


Type 778F2 Transceiver Assy.

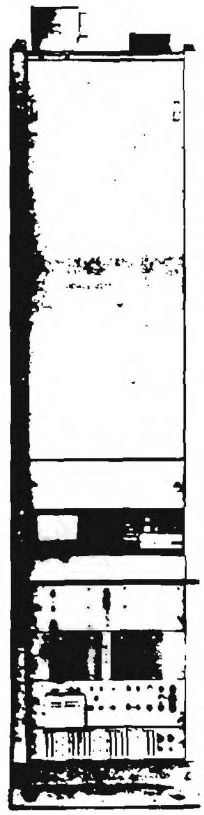


Type 70F1 Transceiver Assy.

Type 775A3 Transceiver Assembly



Type 700F1 RF Repeater



Type 775G2 Heterodyne Repeater

Type 78 radios constitute a family of baseband (remodulating) type microwave systems intended for high-quality transmission performance on short-haul as well as long-haul routes. Equipment is fully solid-state, and has been designed to be extremely easy to install, maintain and expand. Integral testing facilities enable preventive maintenance and quick isolation of trouble. Equipment arrangements include hot-standby, space-diversity, frequency-diversity, multiline switching, and single-channel unprotected.

*48 PCM VF channels can be transmitted over a 778F2A radio in a 3.5 MHz channel using the 9120A digital multiplexer.

Type No: 758B Microwave Baseband Assembly

General Descriptive Publication: Form GTEP 394-582-100 (Message), Form GTEP 394-582-120 (Baseband Switching), Form GTEP 394-582-110 (Video), Form GTEP 394-582-140 (Digital)

The 758B baseband equipment provides various forms of operating characteristics to condition broadband multiplex and video signals for transmission over microwave systems such as the type 75 and the type 78 radio families. Equipment includes such items as lowpass and highpass filters for frequency separation within the baseband, auxiliary baseband amplifiers, emphasis networks, receiver combining or transfer units, and pilot and noise detectors. Choice of optional and accessory items is on a plug-in modular basis. Alarm outputs are provided for connection to an external alarm system.

Type No: 759A FM Modem Assembly

General Descriptive Publication: Form 759A-P4, Form GTEP 394-591-100

The 759A provides baseband modulation and demodulation for type 75 70-MHz IF heterodyne microwave radio systems. The assembly conforms to CCIR Recommendations and is capable of end-to-end operation with the Western Electric FM-3A and similar modems. Three basic arrangements are available: duplex, one-way transmit, and one-way receive.

Type No: 51F Alarm System

General Descriptive Publication: Form 51F-P4, Form GTEP 394-516-100

The 51F provides highly accurate and secure status monitoring of unattended field stations from centralized locations. The 51F will monitor operation of microwave radio repeaters and facilities, cable carrier terminals, telephone community dial offices, TV and radio broadcast transmitters, and utility substations and switching points. As many as eight systems, each reporting the status of 64 functions, can be accommodated on an 8-kHz microwave supervisory channel along with voice communications.

Type No: 52A Order Wire Assembly

General Descriptive Publication: Form GTEP 394-521-101

The 52A provides an AM double-sideband service channel for voice and tone transmission above the video baseband of a microwave radio system. Twenty-one channels are available for tone control and speech circuits between 5.8 and 6.2 MHz.

Type No: 53C Order Wire and Tone Signaling System

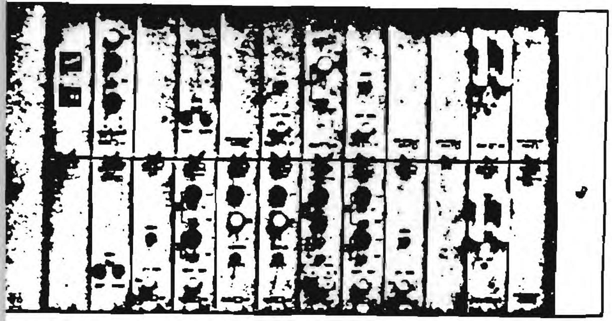
General Descriptive Publication: Form 53C-P4

The 53C is used primarily with microwave radios as a VF order wire service facility, and provides a 1.8-kHz or 2.7-kHz talking channel and up to six signaling tone channels over a standard VF channel.

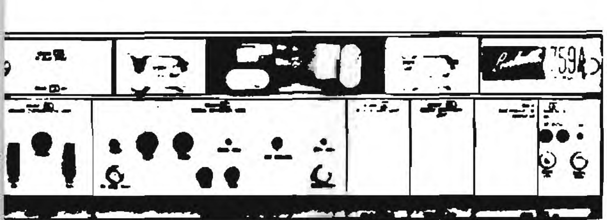
Type No: 54A FM Program Channel

General Descriptive Publication: Form 54A-OM, Form GTEP 394-541-100

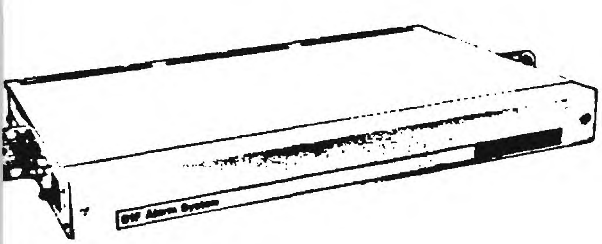
The 54A provides up to four wideband FM channels which may be used to send and receive high quality TV audio, FM music or high-speed data signals above the normal baseband of microwave radio systems. Offered in three basic arrangements, 54A equipment is available using subcarrier frequencies at 6.17, 6.8, 7.5 and 8.27 MHz. Channel bandwidth is 30 Hz to 15 kHz for TV audio or music, and 30 Hz to 100 kHz for data.



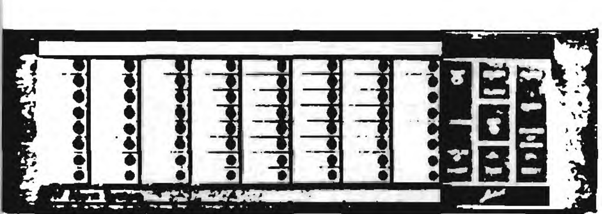
Typical 758B Baseband Assy. For Microwave Systems



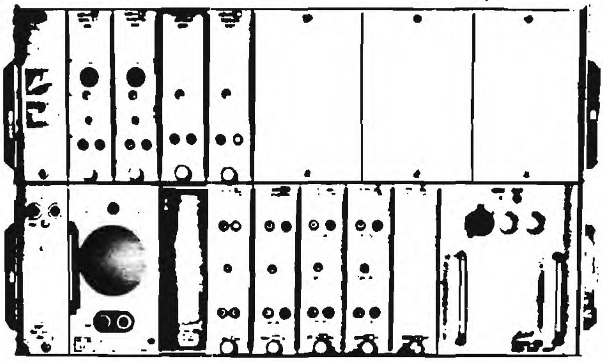
Type 759A FM Modem Assy. For Heterodyne Microwave Radios



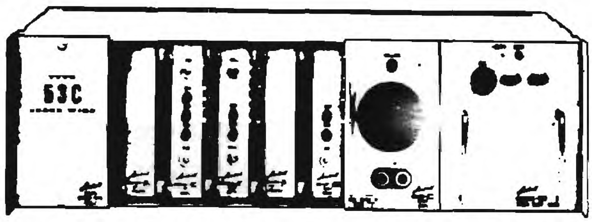
51F Remote Terminal



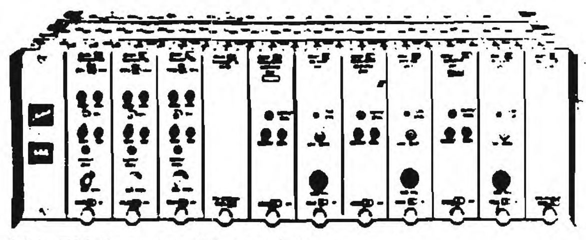
51F Master Terminal



Typical 52A Order Wire
For Video Microwave Systems



Typical 53C Order Wire
For Message Microwave Systems



54A FM Program Channel Assy.
Equipped For Three Duplex Channels

Type No: 757C Multiline Switching System

General Descriptive Publication: Form GTEP 394-573-155 (IF Switch w/o pilots), Form GTEP 394-573-170 (IF Switch), Form GTEP 394-573-110 (Baseband Switch), Form GTEP 394-573-125 (Protected Modem Switch), Form GTEP 394-573-130 (FM Modem Switching), Form GTEP 394-573-135 (Protected Separate Switching)

The 757C provides either baseband or IF protection for up to eight radio channels on a two-for-six basis, and may be used on broadband microwave radio systems with message capacities of up to 1800 channels. At full capability, two protection channels protect six traffic channels, representing a significant savings over one-for-one protection techniques. In addition, modem protection and protection channel access are available.

Type No: 361A Order Wire System

General Descriptive Publication: Form GTEP 342-361-120

The 361A Order Wire System provides a four-channel service facility operating from 516 kHz to 544 kHz and 4 kHz to 56 kHz. Expressly suited for applications where data is transmitted below 516 kHz, such as data under voice networks, the 361A will also operate in lower frequency ranges. A standard assembly for four channels is only 5-1/4 inches high (three rack mounting spaces), and can be installed on a 19-inch rack or on a 23-inch rack.

Type No: 361B Order Wire System

General Descriptive Publication: Form GTEP 342-361-121

The 361B Order Wire System provides a six-channel service facility operating from 516 kHz to 544 kHz and 4 kHz to 56 kHz. Expressly suited for applications where data is transmitted below 516 kHz, such as data under voice networks, the 361B will also operate in lower frequency ranges. A standard assembly for six channels is 5-1/4 inches high (three rack mounting spaces), and can be installed on a 23-inch rack.

KIAL CABLE NSMISSION 'EMS

There has been increased interest in the use of advanced coaxial transmission systems such as the low-density type 46C system and the high-density type 46V system. Coaxial systems of this type may be used effectively in short-haul and long-haul terminal-to-terminal communications, for interconnection of multiplex and microwave radio, for spur routes off of microwave systems, and for metropolitan entrance links. These systems are characterized by their inherent reliability and long-life.

Type No: 46C Coaxial Transmission System

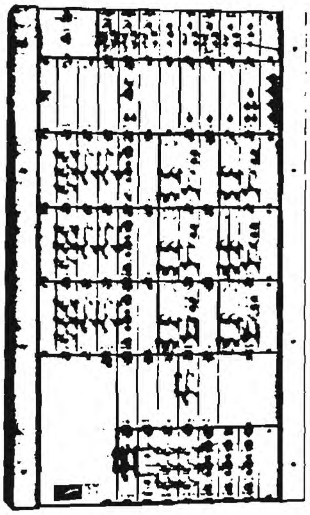
No. of Channels: 300, 600, 720 channels
Frequency Range: 60 kHz to 1300 kHz, or 60 kHz to 3084 kHz
General Descriptive Publication: Form 46C-P4

The 46C system is designed for cable routes of approximately 100 miles or less, and interfaces with 0.174-inch or 0.375-inch coaxial tubes, one tube for each direction of transmission. Use of identical, parallel amplifiers for both transmitter and receiver offers a high degree of reliability. Pressurized housings for repeater installations are available. It is possible to insert additional intermediate repeaters and to change out equalizers to expand outgrown 300-channel systems to 600 or 720 channel capacity for new requirements.

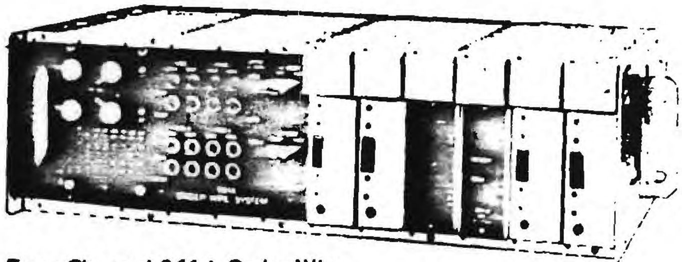
Type No: 46V Coaxial Cable Communications System

No. of Channels: 300, 960, 2700, 1200 + TV, 10,800 per pair of coaxial tubes
Frequency Range: 60 kHz to 61.16 MHz
General Descriptive Publication: Form 46V-PS, Form GTEP 342-464-110, Form GTEP 836-464-070
(Both GTEP's include engineering, installation and maintenance information.)

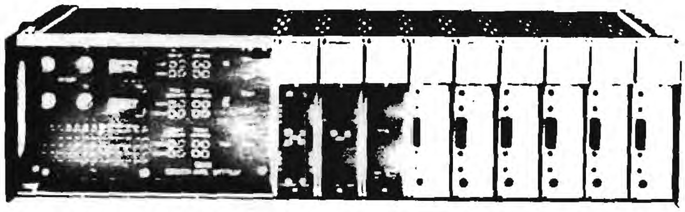
The 46V is a family of high-capacity, broadband coaxial transmission systems economically adapted to short-haul and long-haul communications routes using 0.174-inch and 0.375-inch coaxial tubes. At the time of initial planning and installation, 46V equipment can be engineered to provide very flexible expansion capability by simply adding new repeater locations while also using existing sites. The 46V accepts the broadband signal of channelizing equipment such as the type 46A3 Multiplex System. A simple and proven design, the 46V adheres to CCITT recommendations. Repeater housings are available for three or six bidirectional repeaters.



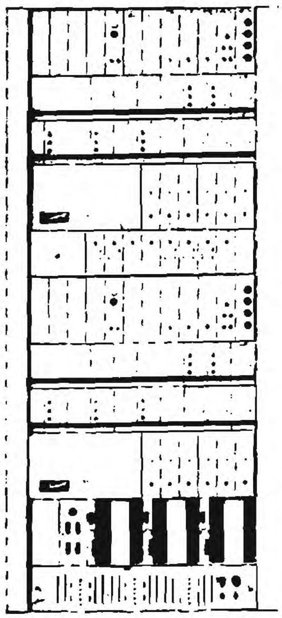
757C Baseband Switching Assy.



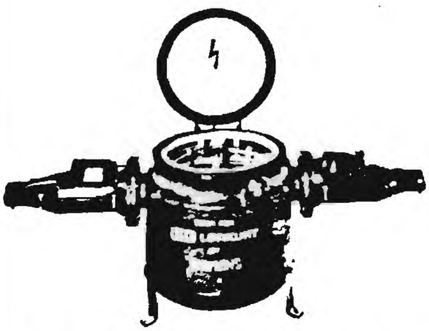
Four-Channel 361A Order Wire
For Data-Under-Voice Microwave Systems



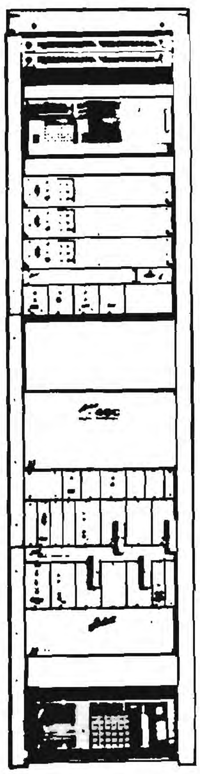
Six-Channel 361B Order Wire
For Data-Under-Voice Microwave Systems



757C IF Switching Assy.



Type 46V Underground Repeater Housing
For Three Bidirectional Repeaters



Office Terminal Assy. Of The
46C Coaxial Transmission System

46V Terminal Assy.
Equipped For Three 2700-Channel
12-MHz Transmission Systems

IPLEX
EMS

GTE Lenkurt offers three basic multiplex systems, the type 36A2, the type 46A3, and the type 46A3-C. A specialized channel equipment assembly, called type 46A6, is also available, and is compatible with Bell System A6 channel bank requirements. All multiplex systems utilize the proven GTE Lenkurt-developed polylithic crystal filter, and miniaturized circuitry.

Type No: 36A2 Multiplex System

No. of Channels: 1-614, Direct-To-Line
Frequency Range: 4-2540 kHz
Channel Freq. Response: 300-3400 Hz, –3.0 dB, +0.85 dB
General Descriptive Publication: Form GTEP 342-361-112
(Includes engineering, installation and maintenance information.)

The 36A2 is a radio multiplex system designed for maximum flexibility in common carrier, industrial and government radio networks. Equipment is the most compact of its kind available – 12 channels per 5-1/4 inch-high shelf. Each channel unit is completely self-contained, and fully synchronized for data transmission applications. A standard 614-channel system is available occupying the frequency range between 4 kHz and 2540 kHz.

Type No: 46A3 Multiplex System

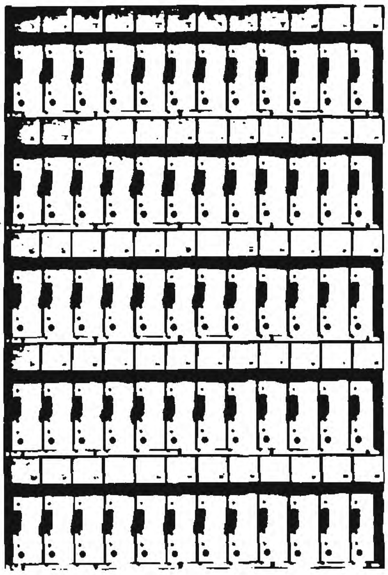
No. of Channels: 1-2400
Frequency Range: 60-11,404 kHz
Channel Freq. Response: 250 to 3450 Hz, –3.0 dB, +0.5 dB
General Descriptive Publication: Form GTEP 342-461-101

The 46A3 is the most advanced long-haul radio multiplex system of its kind available for use on the "heavy route" microwave radio and coaxial cable networks of common carrier, industrial and government users. A complete 600-channel system may be accommodated on three 11'6" equipment racks, and a 2400-channel system occupies thirteen equipment racks. Advanced polylithic filter technology and microelectronic and miniaturized circuitry throughout the 46A3 assure a high degree of reliability, quality performance and long life. Equipment is available in standard configurations including directly formed supergroups (DFSG) and direct-to-line (DTL) channel equipment. "Connectorized" jackfields may be ordered to speed and simplify installation. (Channel equipment designated type 46A6 is available to meet Bell System requirements.)

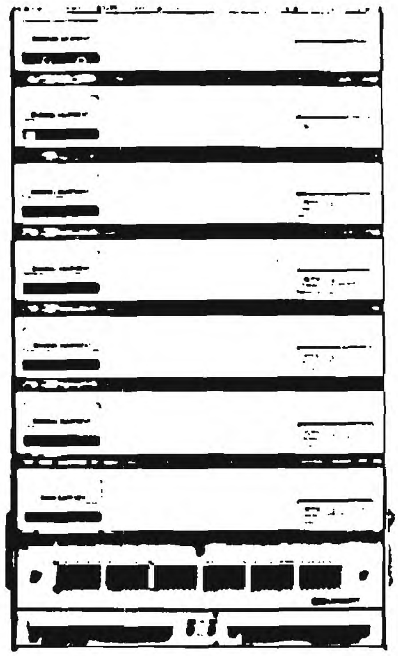
Type No: 46A3-C Multiplex System

No. of Channels: 1-2400
Frequency Range: 12-11,404 kHz
Channel Freq. Response: 300 to 3400 Hz, ±0.8 dB
General Descriptive Publication: Form 46A3-C-P4, Form 342-468-111LC

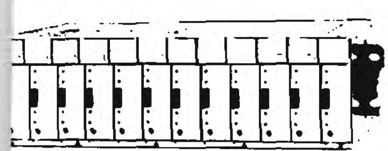
The 46A3-C system achieves direct modulation from voice frequency to basic 60-channel supergroups without use of group equipment. Also, direct-to-line arrangements are possible providing a total of 132 channels arranged for end-to-end compatibility with conventional multiplex systems. Equipment includes built-in out-of-band E&M signaling, which is particularly advantageous for government and industrial communications systems. Polylithic crystal filters and thick-film hybrid techniques are utilized to obtain a high level of reliability and compactness. A 600-channel system may be mounted on three 11'6" racks.



Complete 60-Channel
36A2 Multiplex System

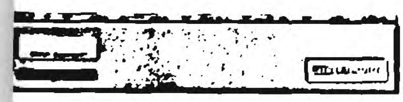


60-Channel Bank Of 46A3 Multiplex System For Directly Formed Super-group and Direct-To-Line Applications

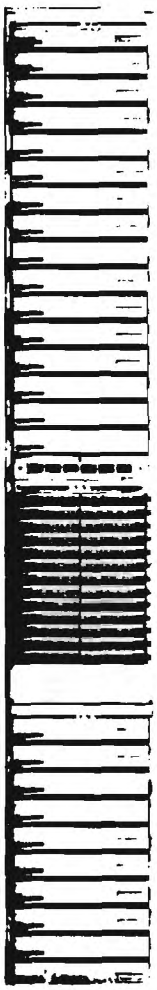


Complete 12-Channel
36A2 Multiplex System

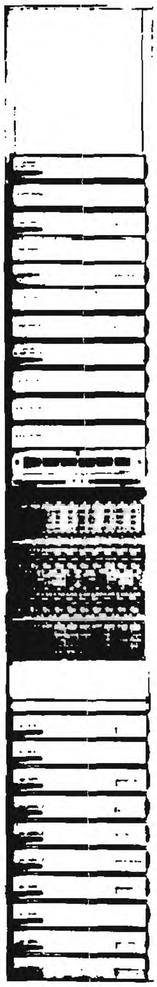
Supergroup Equipment Assy.
For Multiplex Systems.
Capacity One Supergroup



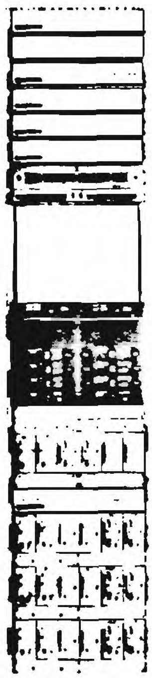
46A3 Group Bank Assy.
For 60 Channels



46A3
Channel
Equipment



46A3
Group/
Supergroup
Equipment



46A3
Mastergroup
and Frequency
Generation
Equipment

. CARRIER
MS

GTE Lenkurt provides a wide variety of frequency-division-multiplex (FDM) carrier systems for use on cable facilities. Compatibility is provided in operation on an end-to-end basis with equivalent Western Electric types N1, N2, and N3 carrier systems using the GTE Lenkurt types 47A/N1, 47A/N2, and 46B systems, respectively.

Type No: 46B Cable Carrier System

No. of Channels: 2-24 on two cable pairs
Frequency Range: 36-132 kHz (low group), 172-268 kHz (high group)
Compatibility with Western Electric Model: End-to-end operation with W.E. N3 Carrier System
General Descriptive Publication: Form 46B-P4, Form GTEP 342-462-100

The 46B is an intertoll and toll-connecting trunk carrier system which uses single-sideband, suppressed-carrier modulation. The system may be used on cable routes up to 200 miles in length. Channels are fully synchronized for data transmission. The 46B system can be linked to microwave. The system utilizes external in-band signaling such as provided by the type 11A Signaling System, and may be equipped with connectorized jackfields.

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EQUIPMENT

Type No: 47A/N1 Cable Carrier System

No. of Channels: 4-12 on two cable pairs
Frequency Range: 36-140 kHz (low group), 164-268 kHz (high group)
Compatibility with Western Electric Model: W.E. N1 Carrier
General Descriptive Publication: Form GTEP 342-471-115
(Includes engineering, installation and maintenance information.)

The 47A/N1 is an economical exchange and toll-connecting trunk carrier system for 200-mile cable routes. The system incorporates E&M out-of-band signaling with converters available for loop signaling. Trunk-make-busy (TMB) with automatic restoral is offered as an option and calling-party forced-release (CPFR) is provided with the loop type signaling. Including signaling and TMB with automatic restoral, a complete 12-channel terminal is only 29-3/4 inches (17 mounting spaces) high. Equipment is designed for fast, simple installation and easy maintenance.

Type No: 47A/N2 Cable Carrier System

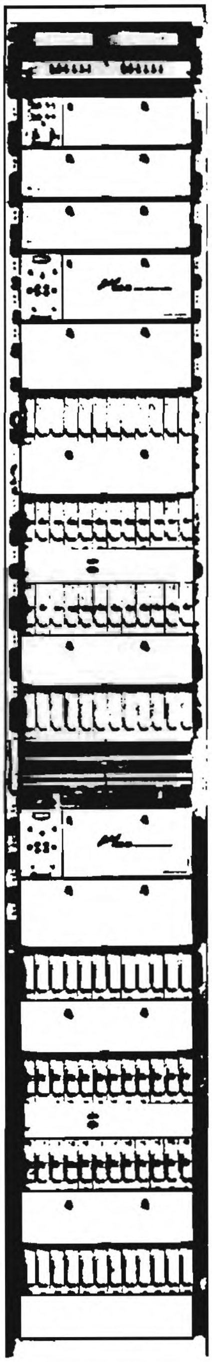
No. of Channels: 4-12 on two cable pairs
Frequency Range: 36-140 kHz, (low group), 164-268 kHz (high group)
Compatibility with Western Electric Model: W.E. N2 Carrier
General Descriptive Publication: Form GTEP 342-471-120
(Includes engineering, installation and maintenance information.)

The 47A/N2 is an intertoll, toll-connecting and exchange trunk carrier system for cable routes up to 200 miles in length. The highly reliable system uses external in-band signaling such as provided by the 11A system. Three standard fully-equipped rack arrangements of the 47A/N2 are available to reduce costs. Included is E&M or loop-dial signaling, standard jackfields, miniature jackfields, or miniature jackfields with connectors installed, four-wire terminating units, repeater power feed, order wire facilities, and filter/fusing assemblies.

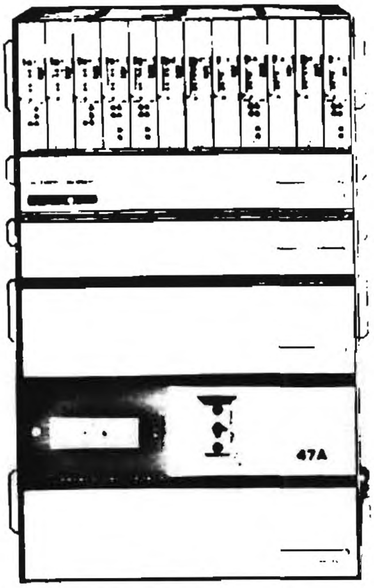
Type No: 948A Repeater and Order Wire Assemblies

General Descriptive Publication: Form GTEP 342-948-110
(Includes engineering, installation and maintenance information.)

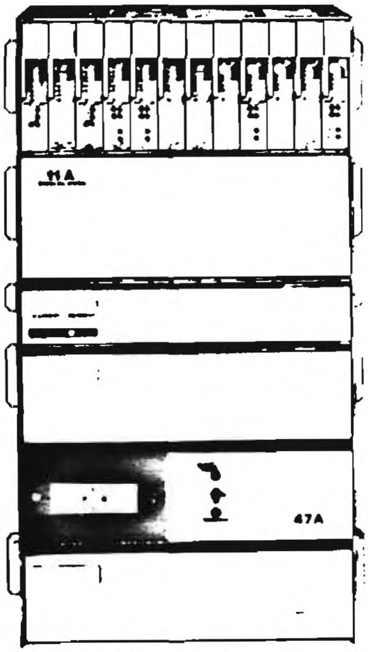
The 948A equipment provides complete repeatered line facilities including order wire assemblies for N-type carrier systems. Repeater equipment may be used for cable transmission routes serving GTE Lenkurt 46B, 47A/N1, 47A/N2 and equivalent systems, and include the repeaters themselves, along with repeater power feed facilities, fusing, and testing equipment to ease maintenance. Two sizes of weatherproof cabinets are available for mounting repeater equipment along the cable route, and may be equipped for up to 6 or 12 N-type carrier systems. Order wire facilities are compatible with equivalent Western Electric equipment and include a terminal system order wire, way station panel for repeater sites, and portable order wire telephone set.



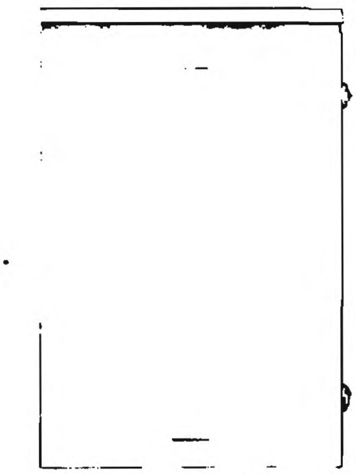
Typical 48-Channel Assy.
Of 46B Cable Carrier System



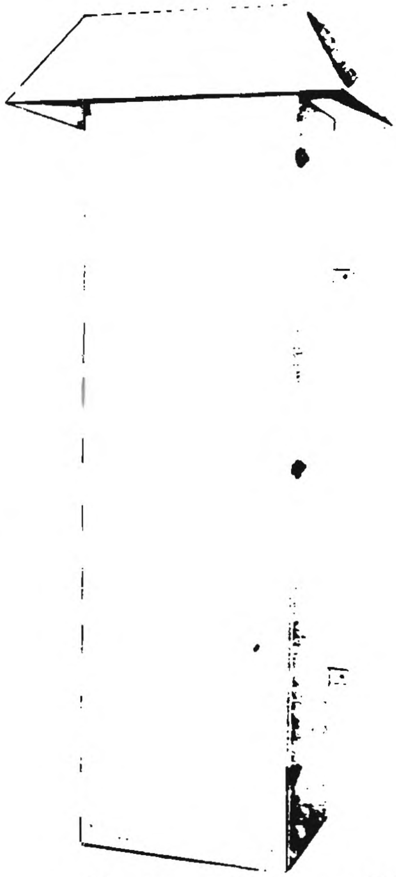
12-Channel 47A/N1 Cable Carrier
Terminal Assy. With Signaling



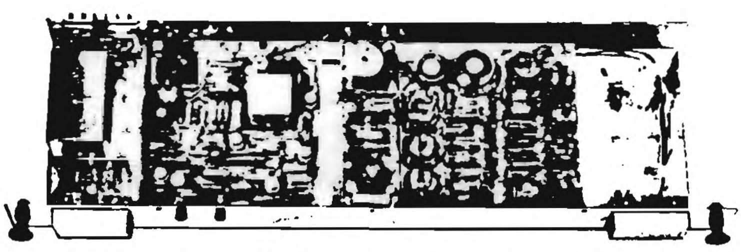
12-Channel 47A/N2 Cable Carrier
Terminal Assy. With Signaling



Weatherproof Equipment Cabinet
Provided For Repeaters
Of 948A Assembly
3' High



Weatherproof Equipment Cabinet
Provided For Repeaters
Of 948A Assembly
7½' High



948A Compact One-Way Cable Repeater For N-Type Carrier Systems

E CARRIER
:MS

GTE Lenkurt provides a complete line of pulse code modulation (PCM) cable carrier systems to meet a constantly increasing demand of the telephone industry for digital transmission facilities. These economical systems fulfill the need for exchange, EAS, toll, and subscriber line services, and feature end-to-end compatibility with equivalent Western Electric systems.

Type No: 9001B PCM Channel Bank
No. of Channels: 1-24 on two cable pairs
Pulse rate: 1.544 megabits/sec
Compatibility with Western Electric Model: W.E. D1 Channel Bank
General Descriptive Publication: Form GTEP 342-911-102

The 9001B is an advanced D1-type PCM cable carrier system for EAS, exchange and toll-connecting trunks. This second-generation equipment has been designed to be extremely reliable and easy to align and maintain. Miniaturized and integrated circuitry are utilized extensively. Channel bank equipment includes built-in signaling and is only 22-3/4 inches (13 mounting spaces) high. T1-type repeatered line equipment for the 9001B is the type 9101C.

Type No: 9002B PCM Channel Bank
No. of Channels: 1-24 on two cable pairs
Pulse Rate: 1.544 megabits/sec
Compatibility with Western Electric Model: W.E. D2 and D3 Channel Banks
General Descriptive Publication: Form GTEP 342-911-107
(Includes engineering, installation and maintenance information.)

The 9002B PCM Cable Carrier System is intended for intertoll trunks with up to 200 tandem regenerators or more. Meeting the overall performance objectives of a W.E. D2 24-channel digroup, the 9002B employs the PCM eight-bit binary encoding format to provide full toll-grade transmission performance. Conversion to D1D or D2 operation is performed simply by inserting a plug-in adapter. The new equipment has available more than two dozen types of plug-in channel/signaling units to supply exchange and subscriber services as well as toll links. Channel bank equipment is 19-1/4 inches (11 mounting spaces) high. T1-type repeatered line equipment for the 9002B is the type 9101C. A subscriber carrier arrangement of the 9002B providing 48 channels is the type 910A.

Type No: 910A PCM Subscriber Carrier System
No. of Channels: 1-48 on four cable pairs
Pulse Rate: 1.544 megabits/sec (each 24-channel system)
General Descriptive Publication: Form GTEP 342-911-104
(Includes engineering, installation and maintenance information.)

The 910A is a special version of the 9002B D2-format PCM Channel Bank arranged for subscriber telephone service. Designed for high quality voice and data service at low cost, and provides single-party, multiparty, paystation and special services. A weatherproof outdoor housing containing the complete facilities for 48 PCM channels is available for pad or platform mounting. The assembly is operated from 117 Vac primary power, and standby batteries are available as a backup. The 910A utilizes the type 9101C PCM repeatered line equipment.

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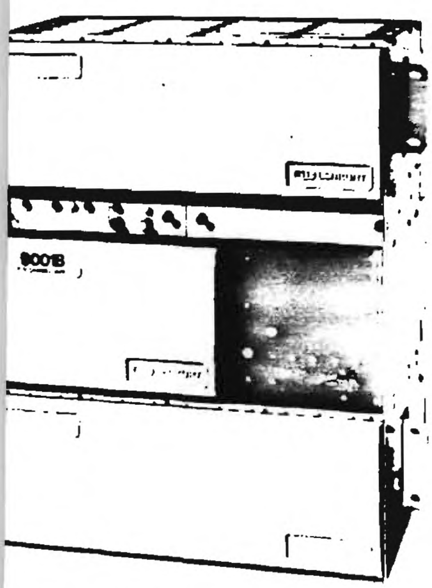
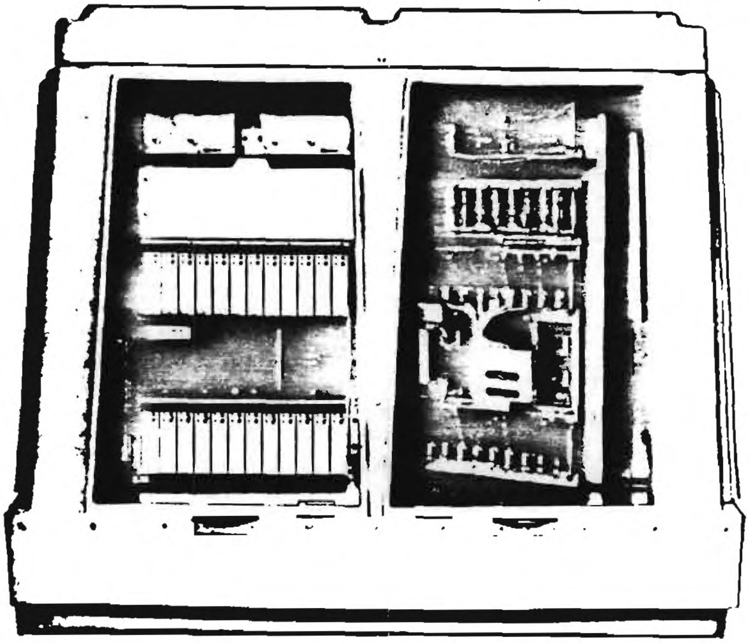
Type No: 9120A Digital Multiplexer
Line Rate: Up to 6.3 Mb/s (96 channels)
Compatibility with Western Electric Model: Meets the compatibility specifications for the M1-2 Digital Multiplex
General Descriptive Publication: Form GTEP 342-911-105, Form GTEP 813-786-075
(Both GTEP's include engineering, installation and maintenance information.)

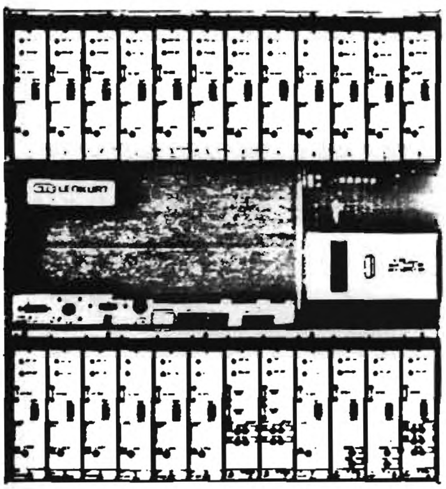
The 9120A is an advanced pulse code modulation digital multiplexer suited for either microwave radio or multipair cable transmission of up to 96 voice-frequency channels. For radio, the digital multiplexer combines two 1.544 Mb/s PCM bit streams using GTE Lenkurt's modified duobinary technique for transmission over the GTE Lenkurt type 778F2A 2-GHz Microwave Radio System. For cable, the digital multiplexer combines four 1.544 Mb/s PCM bit streams for transmission over T2-type repeatered lines or radio.



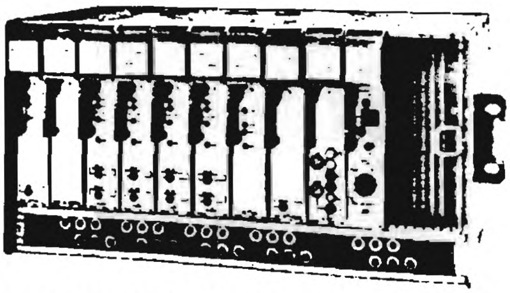
4-Channel D1-Compatible
001B PCM Channel Bank



Easy Rear Access To 910A PCM Subscriber Carrier System
By Rotation Of Rack



24-Channel D3-Compatible
9002B PCM Channel Bank



9120A Digital Multiplexer

Type No: 9121A Synchronous Multiplexer

General Descriptive Publication: Form GTEP 342-911-106

The 9121A combines 1.544 Mb/s bit streams from two clock-synchronized PCM terminals into a bipolar 3.152 Mb/s signal for transmission over a 9102A 48-channel repeatered line. Only 1-3/4 inches high, the multiplexer accepts input signals from GTE Lenkurt 9002B and 910A systems and equivalent PCM systems that are capable of being clock synchronized. An internal clock is provided to synchronize colocated PCM terminals.

Type No: 9101C PCM Repeatered Line Equipment

General Descriptive Publication: Form GTEP 342-910-103, Form GTEP 836-910-072 (Both GTEP's include engineering, installation and maintenance information.)

The 9101C equipment provides complete T1-type span line facilities for D1, D2 and D3 type PCM channel banks, data terminals and subscriber carrier systems such as produced by GTE Lenkurt. Equipment also will operate compatibly with most other manufacturers' PCM carrier systems. The 9101C includes a line terminating shelf; three-, ten-, and twenty-five-system repeater housings; repeaters; order wire; span-line power supplies; and span-line switching. Repeaters are equipped with automatic line build-out (ALBO) equalizers and a conversion plug component for single-cable or two-cable operation, over cable spans equipped with up to 200 tandem repeaters.

Type No: 9102A PCM Repeatered Line Equipment

General Descriptive Publication: Form GTEP 836-910-073

The 9102A equipment provides complete span line facilities for the transmission of 48 PCM carrier derived channels. Transmitting a bipolar 3.152 Mb/s bit stream, the 9102A doubles the channel capacity offered by T1-type span lines. The 9102A includes a line terminating shelf; three-, ten-, and twenty-five-system repeater housings; repeaters; order wire; span-line power supplies; and span-line switching. Repeaters are equipped with two regenerators, and automatic line build-out (ALBO). The repeater is designed for two-cable, or one-cable operation in screen cable, or standard 900-pair cable or larger.

Type No: 9148A PCM Repeatered Line Equipment

General Descriptive Publication: Form GTEP 342-910-104

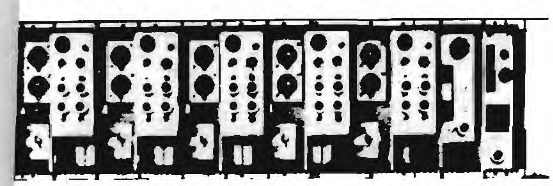
A retrofit system, the 9148A duobinary repeatered line equipment provides the means to double the circuit capacity of a standard 1.544 Mb/s PCM repeatered line from 24 to 48 channels. The 9148A uses the GTE Lenkurt patented duobinary technique to translate a 3.152 Mb/s bipolar bit stream into a format that occupies the same power spectrum as a 1.544 Mb/s signal for transmission over a span line. The 9148A consists of office repeaters, line repeaters and a bridging repeater, all of which mount in most existing GTE Lenkurt and WECO line terminating shelves and repeater housings. The system is compatible in the same sheath or housing with working 9101/T1-type systems and can be used to fill out existing PCM routes.

Type No: 91100 PCM Cable Test Set

General Descriptive Publication: Form GTEP 103-735-100 (Includes operation and maintenance information.)

This simple and easy to operate test set identifies cable pairs suitable for use by PCM T1-type carrier systems. The portable, battery operated unit measures transmission loss, noise and crosstalk, and recognizes such faults as water in the cable, load coils, bridged taps, build-out capacitance, and open or shorted pairs. Extremely versatile, the test set will also indicate the disturbing effect of dedicating another pair in an existing cable to T1-type carrier, and will determine if line repeaters are performing marginally. Included is a carrying case, leather carrying strap, and test cord.

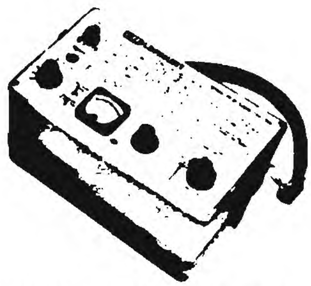
:1A Synchronous Multiplexer
nbines Two 1.544 Mb/s Bit Streams For
nsmission Over a 9102A Repeatered Line or
·8A Repeatered Line



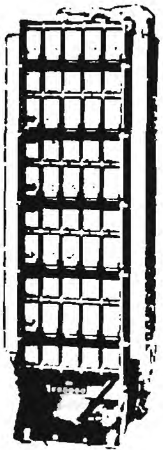
)1C Line Terminating Shelf
r Five D1, D2 Or D3 Compatible
M Cable Carrier Systems

9101C/9102A/9148A
25-Unit Repeater Housing

9101C/9102A/9148A
Three-Unit Repeater Housing

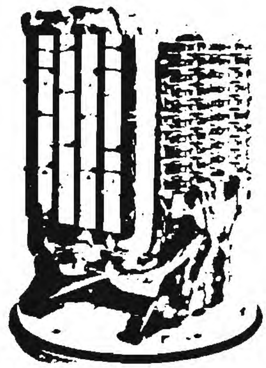


91100 PCM Cable Test Set



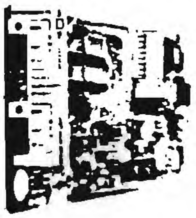
9101C/9102A/9148A
25-Unit Line Repeater
Nest Assembly

9101C/9102A/9148A
10-Unit Repeater Housing



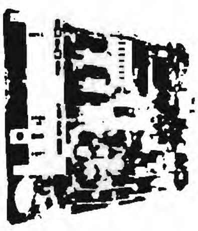
9101C/9102A/9148A
10-Unit Repeater Housing
(Cover Removed)

9148A
Line
Repeater
Unit

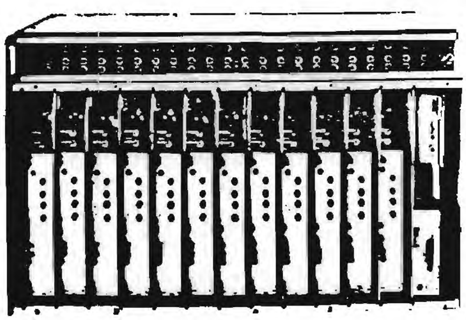


9148A
Office
Repeater
Unit
(Intermediate)

9148A
Office
Repeater
Unit
(Terminating)



9148A
Bridging
Repeater
Unit



9102A Line Terminating Shelf
For Thirteen 48-Channel PCM
Cable Carrier Systems

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GTE Lenkurt makes carrier equipment available for use from the telephone office out to the customer location. Equipment of this type has been produced by GTE Lenkurt for over a decade, and today, the company produces a wide variety of equipment of the subscriber type.

Because of the wide selection of equipment it makes available, GTE Lenkurt is in a position to suggest the most economical and effective system to suit particular needs.

Type No: 82A Station Carrier System

No. of Channels: 1-6 on a single wire pair
Maximum System Length: 20 miles of 19 gauge cable (140 dB at 112 kHz)
Frequency Range: 72-140 kHz (C.O. to Station), 8-56 kHz (Station to C.O.)
Cable/Open Wire Operation: Cable and open wire
General Descriptive Publication: Form 82A-PS, Form GTEP 342-821-100

This economical station carrier system provides six private-lines, 12 two-party lines with divided ringing and ANI, or 24 party-line circuits on a single cable or open wire pair. Channel drops may be located at any point along the cable route. No adjustments are required. Equipment is easy to engineer and install, and permits routes to be sized more closely to anticipated growth. The 82A provides excellent transmission performance—even for data signals – and high reliability, ensuring dependable, maintenance-free operation. REA approved.

Type No: 82B Cable Carrier System

No. of Channels: 1-6 on a single wire pair
Maximum System Length: 28 miles of 19 gauge cable (175 dB at 112 kHz)
Frequency Range: 72-140 kHz (C.O. to Station), 8-56 kHz (Station to C.O.)
Cable/Open Wire Operation: Cable and open wire
General Descriptive Publication: Form 82B/11A-PS, Form GTEP 342-822-110
(Includes engineering, installation and maintenance information.)

The 82B Cable Carrier System, while similar to the 82A System, is specially designed for concentrated locations of channel terminals such as hotels, and temporary facilities for sporting events, emergency needs, etc. Arrangements are provided for both 82B signaling and type 11A signaling with a variety of signaling facilities to provide interoffice transmission, FX service and subscriber service. The frequency plan of the 82B meets industry standards for station carrier equipment such as GTE Lenkurt's type 82A, 83A and 84A systems. A 1200-ohm loop is provided beyond the station end (outlying six-channel terminal) for single-party subscriber service.

Type No: 83A Single-Channel Station Carrier System

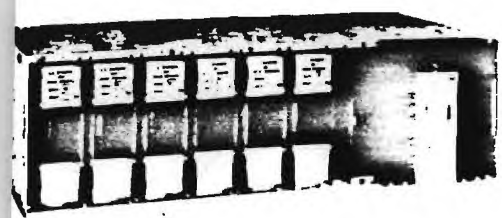
No. of Channels: 1 plus the physical circuit on a single wire pair
Maximum System Length: 7 miles of 19 gauge cable (37 dB at 64 kHz)
Frequency Range: 64 kHz (C.O. to Station), 28 kHz (Station to C.O.)
Cable/Open Wire Operation: Cable and open wire
General Descriptive Publication: Form 83A-P4, Form GTEP 342-831-100/ 478-403-100

The 83A is a very high-quality single-channel station carrier system used by the telephone industry for second lines on the same premises as well as initial service to a new customer. Designed for the same reliability as the pair over which it operates, the 83A may be used wherever physical circuits are already filled. Normal service or operating performance of the physical circuit is not affected in any way. The equipment may be used to improve the quality of a subscriber circuit for data transmission. Fully automatic level regulation is provided and no adjustments of any kind are required.

Type No: 84A Single-Channel Station Carrier System

No. of Channels: 1 plus the physical circuit on a single cable pair
Maximum System Length: 7.5 miles of 19 gauge cable (43 dB at 76 kHz)
Frequency Range: 76 kHz (C.O. to Station), 28 kHz (Station to C.O.)
Cable/Open Wire Operation: Cable
General Descriptive Publication: Form GTEP 342-841-110
(Includes engineering, installation and maintenance information.)

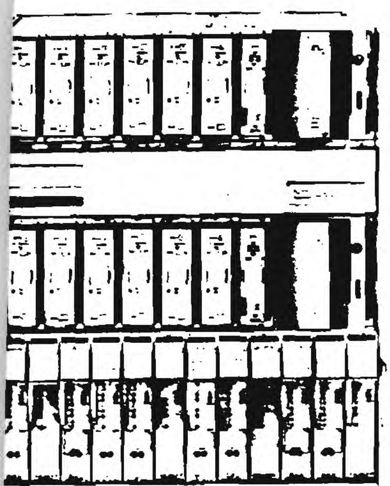
The 84A Single-Channel Station Carrier is a new highly reliable type of subscriber system designed for extremely low-cost circuit additions. Two types of compact C.O. mounting units are available using the same channel unit: one is a 12-channel shelf for standard 19-inch wide rack mounting, and the other is a five-channel assembly designed for mainframe mounting. The 84A is as simple to install and maintain as an ordinary subset. No adjustments required.



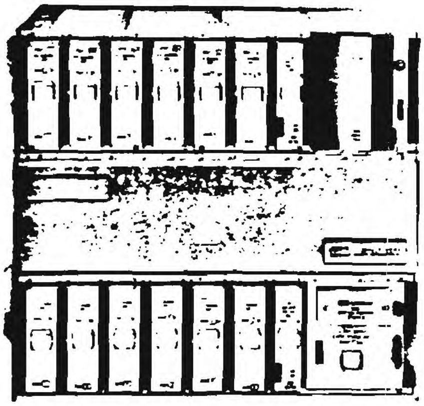
‹-Channel 82A
ation Carrier System

84A Station Unit
Outdoor Housing
(with cover removed)

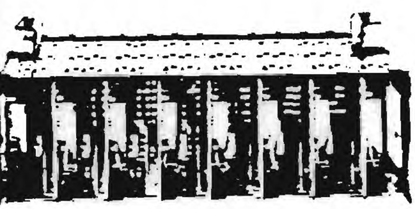
82A
Waterproof
Housing



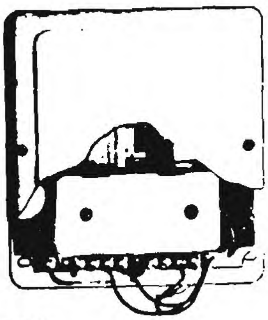
2B 12-Channel C.O. Terminal
Vith 11A Signaling



82B 12-Channel C.O. Terminal
With 82B Signaling



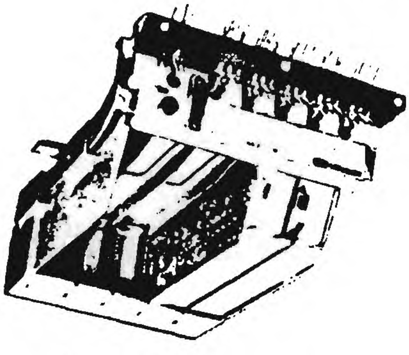
ight-Channel 83A C.O. Terminal



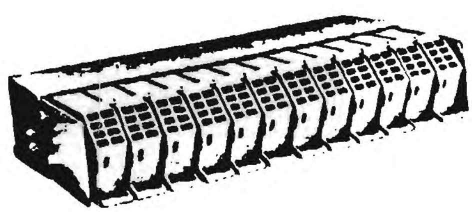
83A
Station Channel Unit

Line Repeater For
82A and 82B Systems

4A
tation Channel Unit



Five-Channel
84A Mainframe Mounted
C.O. Terminal



12-Channel
84A 19" Rack Mounted C.O. Terminal

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ied)

Type No: 821B Terminal Housing Assemblies (Packaged 82B Cable Carrier System)

No. of Channels: 24 on four cable pairs (four six-channel systems)
Frequency Range: For each six-channel system, 72-140 kHz (C.O. to Station), 8-56 kHz (Station to C.O.)
Cable/Open Wire Operation: Cable
General Descriptive Publication: Form 82B/11A-PS, Form GTEP 342-822-110 (Includes engineering, installation and maintenance information.)

The 821B is designed to allow fast, economical expansion of telephone service from a central office to a business, industrial or high-density residential site. A specially engineered and packaged version of the type 82B system, the 821B may be mounted in either an indoor cabinet enclosure for installation in a closet, basement, or other out-of-the-way location on a customer's premises, or an outdoor enclosure for mounting on a pad, pole or platform. The 821B is ideally suited for emergency restoration purposes and for temporary facilities, as well as permanent installations.

Type No: 910A PCM Subscriber Carrier System

No. of Channels: 1-48 on four cable pairs
Pulse Rate: 1.544 megabits/sec (each 24-channel system)
Cable/Open Wire Operation: Cable
General Descriptive Publication: Form GTEP 342-911-104
(Includes engineering, installation and maintenance information.)

The 910A is a special version of the 9002B D2-format PCM Channel Bank arranged for subscriber telephone service. Designed for high-quality voice and data service at low cost, the 910A can operate with 200 or more tandem regenerators, and provide single-party, multiparty, paystation and special services. A weatherproof outdoor housing containing the complete facilities for 48 PCM channels is available for pad or platform mounting. The assembly is operated from 117 Vac primary power, and standby batteries are available as a backup. The 910A utilizes the type 9101C PCM repeatered line equipment.

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GTE Lenkurt has provided data transmission systems to telephone companies and to many industries such as railroads, pipelines, utilities, the government, wire services, and others for a quarter of a century. Having developed the duobinary technique, GTE Lenkurt is well recognized as an innovator in the field of data communications.

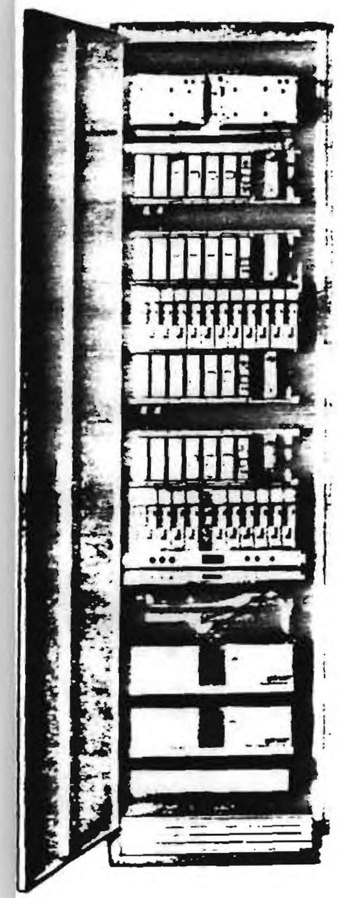
Type No: 25B/108 Data Line Extender

Data Speed (b/s): 300
No. of Data Ch. Provided: 1
Max. Bandwidth Reqt: 600-3000 Hz
Compatibility: End-to-end compatible with W.E. private line station equipment
General Descriptive Publication: 25B/108-PS

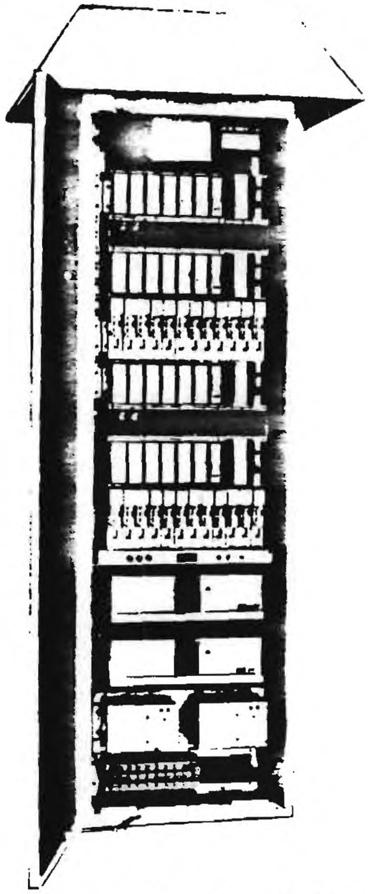
The 25B/108 Data Line Extender is a low-cost data set that extends teletypewriter or data circuits to a subscriber location, eliminating requirements for DC pulses over metallic local loop circuits. The unit is a two-section module consisting of a transmit and a receive branch, which together provide one duplex data communication channel. The 25B/108 converts asynchronous, low-level binary signals to a frequency-shift output for transmission over voice-frequency facilities at rates of up to 300 bits per second.

Type No: 25C Data Transmission System

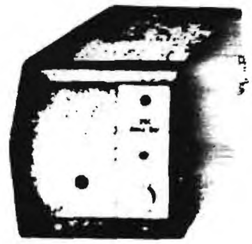
Data Speeds (b/s)	No. of Data Channels	Channel Spacing	Frequency Range
75	25	120 Hz	360-3360 Hz
110	18	170 Hz	340-3400 Hz
150	12	240 Hz	360-3420 Hz
200	21	340 Hz	680-7820 Hz
300	5	480 Hz	840-3240 Hz
600	4	960 Hz	840-2760 Hz (2 Channels) & 4380-6300 Hz (2 Channels)



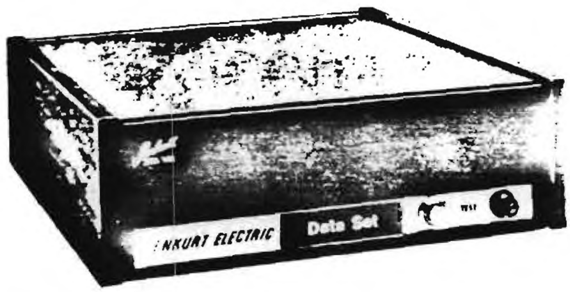
24-Channel 821B Terminal Housing Assembly in Indoor Enclosure



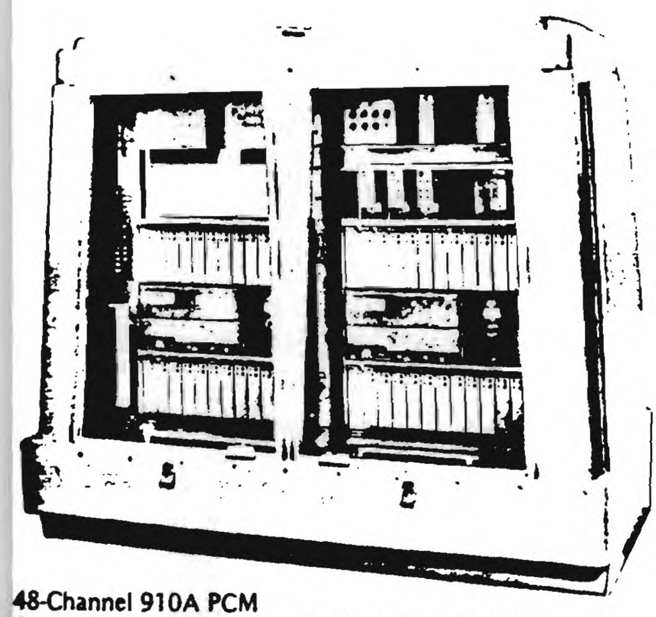
24-Channel 821B Terminal Housing Assembly in Outdoor Enclosure



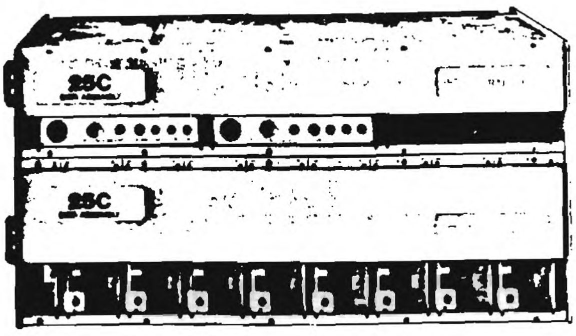
25C Single-Channel Data Subset



25B/108 Data Set



48-Channel 910A PCM Subscriber Carrier System in Weatherproof Cabinet



25C Eight-Channel Rack Assembly

Compatibility: EIA RS-232-C, CCITT V.24, Unipolar (S-level), TTL logic, W.E. 43A1/43B1 line frequency compatible
General Descriptive Publication: Form GTEP 350-253-100
(Includes engineering, installation and maintenance information.)

The 25C is a low-speed voiceband data multiplexer that provides multispeed capabilities. A choice of a single-channel data subset or eight-channel rack assembly is available. The 25C incorporates all of the features needed for efficient data communications, including data rates, interfaces and transmission levels for point-to-point, multipoint and polling data applications.

Type No: 25D Telegraph Transmission System

Data Speeds (b/s)	No. of Data Channels	Channel Spacing	Frequency Range
75	25	120 Hz	360-3360 Hz
110	18	170 Hz	340-3400 Hz
150	12	240 Hz	360-3240 Hz
200	8	340 Hz	510-3230 Hz
200	21	340 Hz	680-7820 Hz

Compatibility: W.E. 43A1/43B1 line frequency compatible, CCITT compatible at 50, 100 and 200 baud rates, standard loop options
General Descriptive Publication: Form GTEP 350-254-100

The 25D is a low-speed voiceband telegraph transmission system offering 20 mA to 60 mA polar and neutral loop options. A choice of a single-channel subset or eight-channel rack assembly is available. The 25D is designed for long distance switched networks of common carriers and for private-line telegraph circuit requirements of business and industry.

Type No: 26C Data Set

Data Speed (b/s): 150/300/600/1200/2400
No. of Data Ch. Provided: 1
Max. Bandwidth Reqt: 600-3000 Hz
Compatibility: EIA RS-232-C, CCITT V.24, MIL-STD-188C
General Descriptive Publication: Form 26C-P4, Form GTEP 350-263-100

This extremely accurate and efficient voiceband data set uses GTE Lenkurt's duobinary technique. An optional secondary channel is also available. The 26C is particularly suited for full-duplex point-to-point, half-duplex multipoint polled applications on a party-line basis, and simplex arrangements for communications between computers, business machines and other data devices requiring accurate transmission. Available as a subset or rack mounted.

Type No: 26C/40.8 Data Set

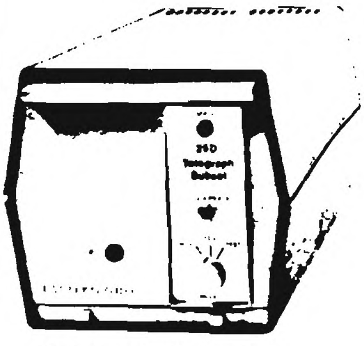
Data Speed (b/s): 20,400/40,800
No. of Data Ch. Provided: 1
Max. Bandwidth Reqt: 10.2-51.0 kHz
Compatibility: W.E. 301B and 303G, MIL-STD-188C
General Descriptive Publication: Form 26C/40.8-PS, Form GTEP 350-263-111

The 26C wideband data set is designed for high accuracy in computer-to-computer transmission. Using GTE Lenkurt's duobinary technique, the 26C may be ordered for four types of standard network arrangements: simplex, half-duplex, full-duplex or multipoint. Available as a desk-top subset or for rack mounting.

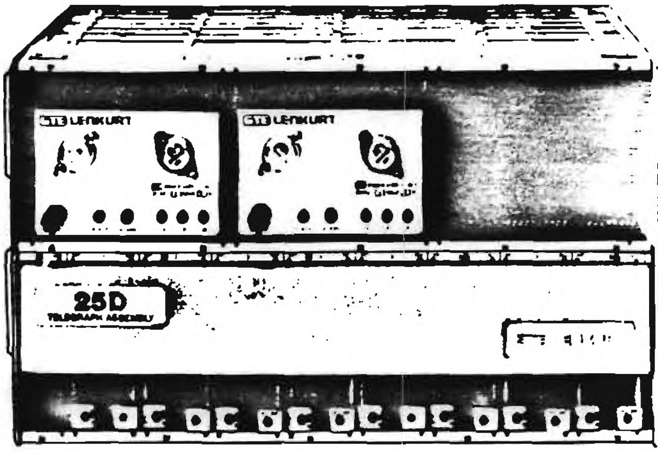
Type No: 261A 2400 bps Data Set

Data Speed (b/s): 2400
No. of Data Ch. Provided: 1
Max. Bandwidth Reqt: 600-3000 Hz
Compatibility: EIA RS-232-C and EIA RS-334
General Descriptive Publication: Form 261A-PS, Form GTEP 350-261-100
(Includes engineering, installation and maintenance information.)

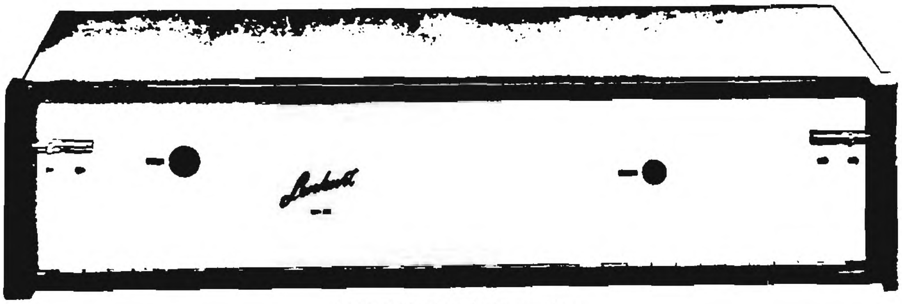
The 261A is a new low-cost data set that accurately and efficiently processes serial digital data signals at 2400 bits per second using GTE Lenkurt's duobinary technique for transmission over a standard 3-kHz voice channel. It is end-to-end compatible with equivalent GTE Lenkurt type 26C1-30016 data sets.



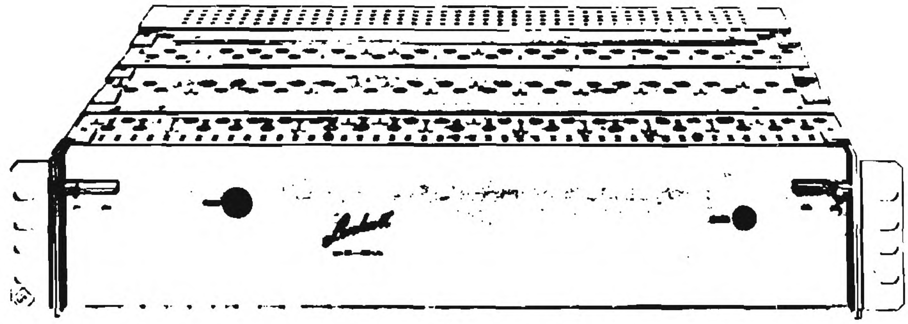
25D Single-Channel
Telegraph Subset



25D Eight-Channel Rack Assy.



26C 2400 b/s Data Set



26C 40.8 kb/s Data Set

261A 2400 bps Data Set

Type No: 262A 4800 bps Data Set
Data Speed (b/s): 4800
No. of Data Ch. Provided: 1
Max. Bandwidth Reqt: 600-3000 Hz
Compatibility: W.E. 208A Data Set, EIA Standard RS-232-C, CCITT Recommendation V.24
General Descriptive Publication: Form GTEP 350-262-100
(Includes engineering, installation and maintenance information.)

The 262A is a new high-speed data set that processes 4800 bits-per-second data for transmission over a 3-kHz voice channel. Incorporating automatic adaptive equalization, the 262A is particularly suited for multipoint polling system applications. It provides a standard EIA RS-232-C interface for connection to business machines, computers, instrumentation systems and other data terminal equipment.

Type No: 262B (208B) 4800 bps Data Set
Data Speed (b/s): 4800
No. of Data Ch. Provided: 1
Max. Bandwidth Reqt: 600-3000 Hz
Compatibility: W.E. 208B Data Set, EIA Standard RS-232-C, CCITT Recommendation V.24
General Descriptive Publication: Form GTEP 350-262-100
(Includes engineering, installation and maintenance information.)

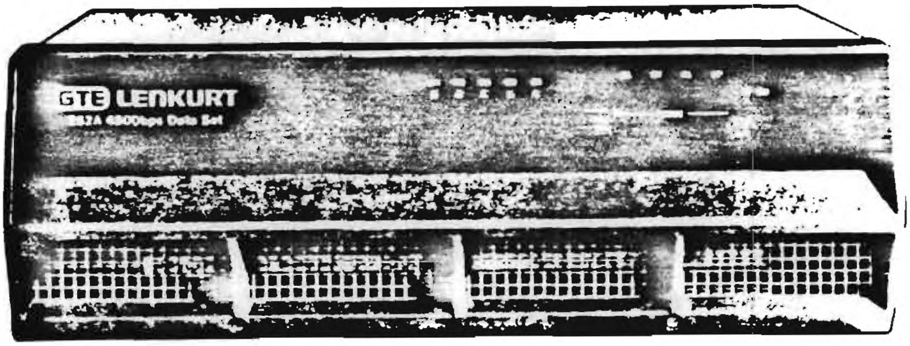
The 262B (208B) is an automatically equalized, high-speed data set, which transmits and receives synchronous serial binary data at a rate of 4800 bits per second. The set operates over the switched (DDD) telephone network or equivalent private switched facilities and features rapid turnaround when operating in the half-duplex, controlled carrier mode. A standard, switch-selected feature of the set is automatic answering which allows the unit to answer incoming calls and receive data while unattended. Alternate voice/data operation or automatic call origination is provided through the use of appropriate ancillary equipment.

Type No: 960B Journal Data Transmission System
Data Speed (b/s): 110 or 200
No. of Data Ch. Provided: 18 at 110 baud, 21 at 200 baud
Channel Spacing: 170 Hz or 340 Hz
Max. Bandwidth Reqt: 340-3400 Hz or 680-7820 Hz
Compatibility: Meets AAR operational standards
General Descriptive Publication: Form 960B-OM
(Includes engineering, installation and maintenance information.)

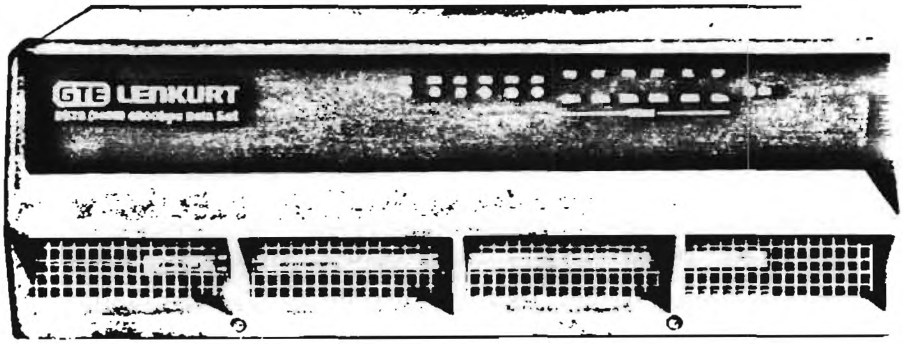
The 960B Journal Data Transmission System provides reliable communication of railroad "hot box" information from trackside to a central location. Also includes the capability to transmit information from dragging railroad equipment, loose wheels and broken flanges. The system operates in conjunction with all monitoring and recording equipment that meets AAR operational standards. Transmission tones are fully compatible with data, telegraph and centralized traffic control (CTC) tones.

Type No: L500A Data Service Unit
Data Speed (b/s): 2400, 4800, 9600 and 56000
No. of Data Ch. Provided: 1
Frequency Range: Operates over 4-wire non-loaded cable loop facilities
Compatibility: W.E. 500A Series, EIA Standard RS-232-C and RS-334 (subrate data and timing), CCITT Recommendation V.35 (56 k/bs data and timing)
General Descriptive Publication: Form 350-650-100
(Includes engineering, installation and maintenance information.)

The L500A provides the interface, logic, and timing circuitry to process data terminal equipment (DTE) signals for entry into the digital data system (DDS) hierarchy. The DSU converts standard EIA or CCITT binary signals to a bipolar with zero substitution format for transmission over the local telephone loop at a selected speed of 2.4, 4.8, 9.6 or 56 k/bs. The DSU furnishes network protection, automatic loop build-out, maintenance loop-around testing capability, regeneration of receive line signals, and recognition and generation of DDS control codes.

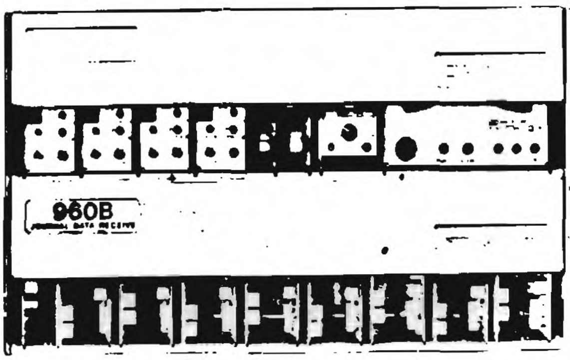


262A 4800 bps Data Set

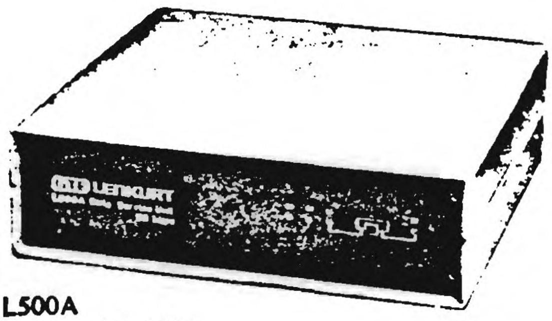


262B (208B) 4800 bps Data Set

960B Remote Transmit Terminal
For Journal Data Transmission



960B Receive Terminal
Equipped For Processing Journal Data
From Four Locations



L500A
Data Service Unit

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Type No: L550A Channel Service Unit

Data Speed (b/s): 2400, 4800, 9600 and 56000
No. of Data Ch. Provided: 1
Frequency Range: Operates over 4-wire non-loaded cable loop facilities
Compatibility: W.E. 550A Series, EIA Standard RS-232-C and RS-334 (subrate data and timing), CCITT Recommendation V.35 (56 k/bs data and timing)
General Descriptive Publication: Form 350-650-100
(Includes engineering, installation and maintenance information.)

The L550A is designed to connect to the digital data system (DDS), data terminal equipment (DTE) that provides its own built-in timing, recovery and logic circuitry. Operating over the local data loop at a selected speed of 2.4, 4.8, 9.6 or 56 k/bs, the L550A provides level adjustment and equalization functions. The CSU supplies network protection and remotely controlled loopback features for delineating between DDS and DTE failures.

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Type No: 971B Adjustable Equalizer

General Descriptive Publication: Form 971B-PS, Form GTEP 350-972-100

The 971B rapidly conditions circuits for high-speed voiceband data transmission. A single equalizer consists of five sections of cosine amplitude equalization, two powerful low- and high-frequency booster amplifiers and fourteen sections of delay equalization.

Type No: 973A Wideband Modulator

General Descriptive Publication: Form 973A-PS, Form GTEP 342-973-100

The 973A converts the frequency range of a 50 kb/s data signal to a range suitable for transmission over a GTE Lenkurt type 47A/N2 carrier system. Direct compatibility is provided with Western Electric's type N2WM-2 Wideband Modem.

Type No: 5249A Speech Plus Data Panel

General Descriptive Publication: Form GTEP 350-000-100, Form 5249A-PS, Form 5249A-S

The 5249A permits voice and data signals to be transmitted simultaneously over a single voice channel. Various filter options are available to allow operation with standard low-speed data multiplex systems such as types 25C and 25D.

Type No: 42520 Data Coupler Unit

General Descriptive Publication: Form GTEP 350-000-100

The 42520 permits one data terminal to be selectively coupled to one of two data channels or vice versa. The unit is capable of coupling data terminals operating at speeds up to 9600 bps and operates with controllers, terminals and modems requiring EIA Standard RS-232-C or CCITT V.24 interfaces.

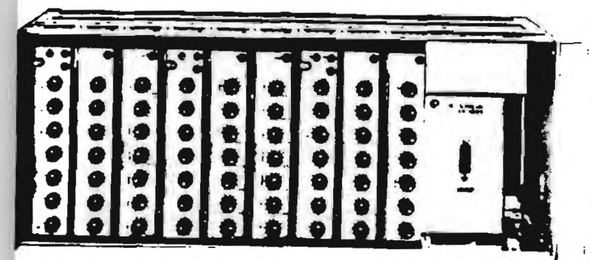
RVISORY
NTROL
EMS

Type No: 51F Alarm System

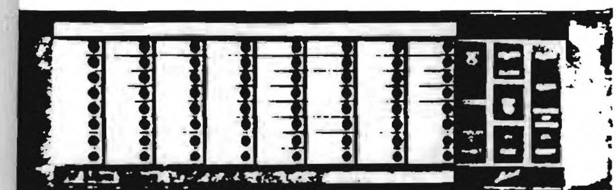
No. of Channels: 64 alarms per tone frequency (17 tone frequencies)
Max. Bandwidth Reqt: 2100-8000 Hz
General Descriptive Publication: Form 51F-P4, Form GTEP 394-516-100

The 51F provides highly accurate and secure status monitoring of unattended field stations from centralized locations. As many as eight master terminals, each reporting the status of 64 functions, can be accommodated on an 8-kHz microwave supervisory channel along with voice communications.

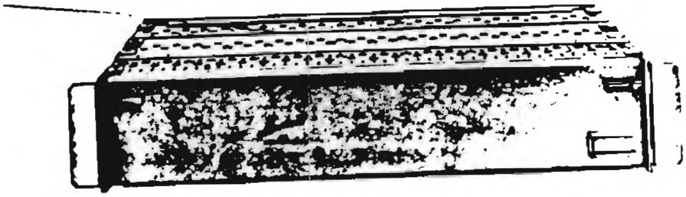
L550A
Channel Service Unit



71B Adjustable Equalizer Assy.
quipped With Three Complete Equalizers

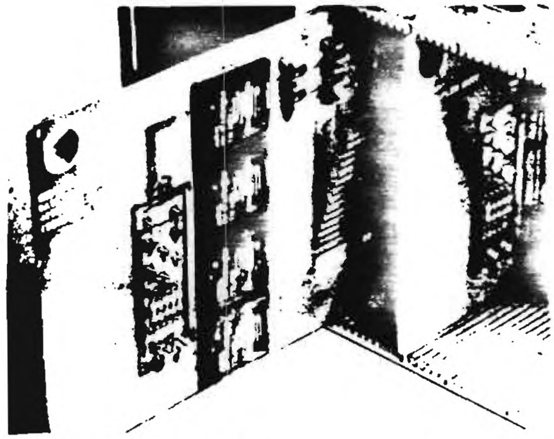


1F Master Terminal

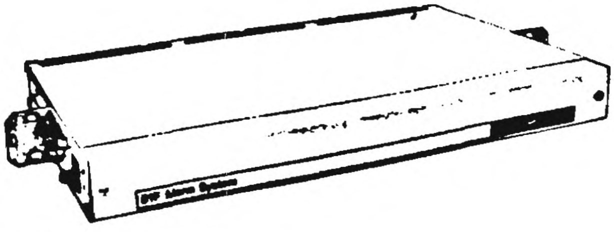


973A Wideband Modulator

5249A Speech-Plus-Data Panel



42520 Data Coupler Unit



51F Remote Terminal

RVISORY
NTROL
EMS
inued)

Type No: 51K2 Telecontrol System

No. of Remote Stations: Up to 63 per single tone frequency channel
No. of Telecontrol Functions (per station): Up to 255 functions per station
Max. Bandwidth Reqt: 425-3315 Hz (18 channels at 110 baud)
850-7650 Hz (21 channels at 200 baud)
General Descriptive Publication: Form 51 Series-P4

The 51K2 provides high-security control of up to 255 latching or non-latching relays at each of 63 different stations. By using a 12 bit Bose-Chaudhuri-Hoequengheim (BCH) cycle check, improper operation due to transmission errors is virtually eliminated. Additional system security may be obtained by operating the equipment in conjunction with the 51L Status Reporting System to provide a "confirm before operate" arrangement.

Type No: 51L2 Status Reporting System

No. of Remote Stations: Up to 21 remote stations per tone frequency channel
No. of Supervised Points Per Remote Station: 32 to 2048 in increments of 32 points
Max. Bandwidth Reqt: Limited only by transmission media considerations (channels at 110, 200, 300, and 600 baud)
General Descriptive Publication: Form 51 Series-P4

The 51L2 Status Reporting System provides high-security transmission of 32 to 2048 binary status data points. Up to 21 remote stations, each using a different frequency allocation, can share a single VF tone transmission facility. A 12 bit Bose-Chaudhuri-Hoequengheim (BCH) cycle check virtually eliminates improper operation due to transmission errors. Solid state light emitting diode (LED) displays are optionally available for data presentation.

Type No: 937B Protective Relaying System

No. of Channels: 7 protective channels and 1 pilot channel
Max. Bandwidth Reqt: 1190-3230 Hz; 595 Hz pilot
General Descriptive Publication: Form 937B-P4

This protective relaying system transmits tripping or fault information for high-voltage transmission systems over standard communications facilities. Featured by the advanced equipment are extremely fast response, high current output, and maximum reliability.

Type No: 962A CTC Protection System

General Descriptive Publication: Form 962A-OM
(Includes engineering, installation and maintenance information.)

The 962A is an automatic transfer facility for tone, data and voice channels on physical, carrier and radio transmission facilities. Providing a wide degree of application flexibility and easy expandability, the 962A is suited for railroad centralized traffic control (CTC) operations and other monitor and control systems where circuit protection is of highest importance.

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ALING
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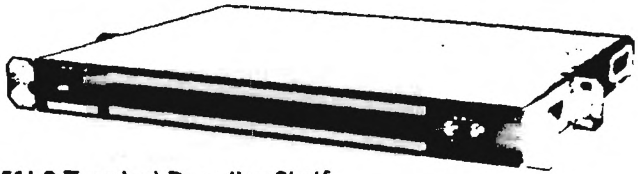
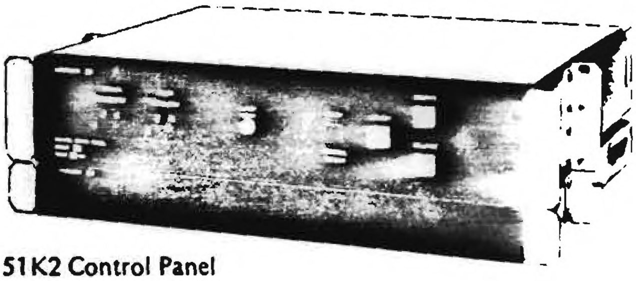
Type No: 11A Signaling System

General Descriptive Publication: Form GTEP 342-111-109 (Engineering and Ordering), Form GTEP 342-111-110 (Functional Description), Form GTEP 342-111-111 (Installation, Alignment and Maintenance)

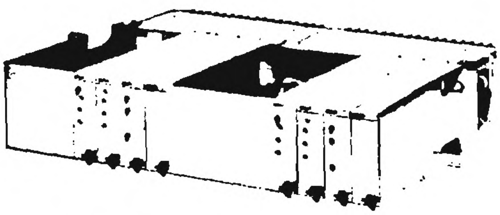
An entirely new concept in signaling systems, the 11A provides low cost, flexible arrangements for two- and four-wire E&M, loop, two- and four-wire FX, and manual/automatic ringdown signaling, two-wire and four-wire DX, along with various optional features, such as trunk-make-busy, calling-party forced-release, built-in precision four-wire hybrids, and switchable attenuators for level coordination. Specialized units such as a DX signaling unit and a single-frequency converter unit with built-in 2600-Hz oscillator also are available. The low-cost system is end-to-end compatible with the Western Electric E and F type signaling and GTE Lenkurt type 927A signaling.



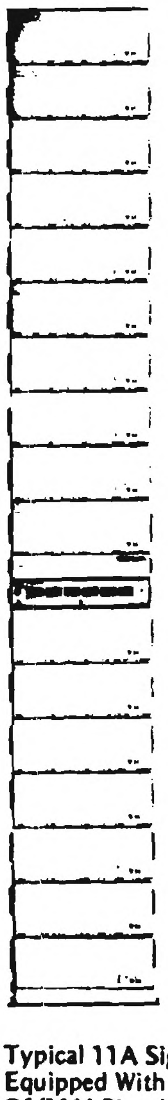
51L2 Terminal Decoding Shelf



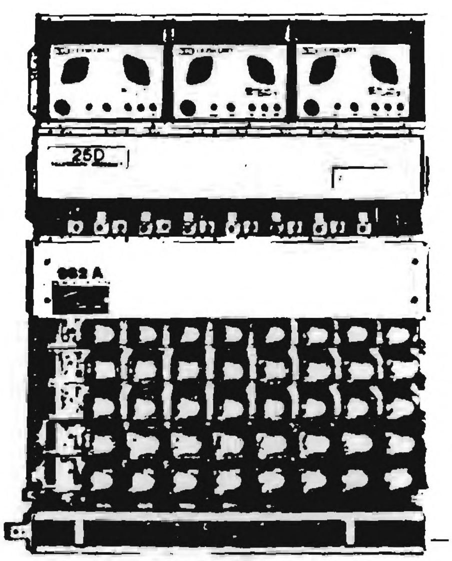
51K2 Control Panel



937B Protective Relaying System



Typical 11A Signaling Assy.
Equipped With 408 Channels
Of E&M Signaling



962A CTC Protection System

Type No: 11A Common Channel Signaling System (CCSS)

General Descriptive Publication: Form GTEP 342-111-100
(Includes engineering, installation and maintenance information.)

The 11A Common Channel Signaling System (CCSS) offers a low-cost alternative to conventional in-band, single-frequency signaling in many applications. Equipment functions by assigning up to 24 telephone signaling circuits to a single common voice channel through a process which separates the signaling functions from the individual carrier or multiplex channels. The equipment is less complex and hence more economical than in-band signaling systems, is immune to talk-down or talk-off, and reduces loading, thereby improving the overall performance of radio transmission facilities. Options include loop, two- and four-wire E&M, loop start FX, and DX signaling.

Type No: 11A Special Service Station Equipment

General Descriptive Publication: Form GTEP 342-111-115
(Includes engineering, installation and maintenance information.)

The 11A Special Service Station Equipment provides low-density signaling and VF terminating arrangements for private line/special service applications. Arranged on a plug-in basis, the equipment performs such functions as off-premises extensions, data connecting facilities, foreign exchange circuits, PBX tie-lines, conference bridges and VF drop facilities. The equipment is available in specially packaged private line station assemblies (111A and 111B) or in a shelf arrangement (1197B) for rack mounting.

Type No: 12A VF Repeaters & DX Signaling Equipment

General Descriptive Publication: Form GTEP 342-121-110

This new and flexible family of equipment is used for voice-frequency amplification and signaling extension between carrier and physical facilities, and for use over physical facilities alone. A comprehensive line of plug-in modular units includes two-wire to two-wire VF repeaters, two-wire to four-wire VF repeaters, four-wire to four-wire VF repeaters, two-wire to four-wire VF repeaters with DX signaling, DX signaling units with or without repeat coils, and precision attenuators. VF repeaters are available with 600-ohm or 900-ohm impedance matching circuitry.

Type No: 931C Echo Suppressor

General Descriptive Publication: Form 931C-P4, Form GTEP 300-931-110

The 931C is a CCITT compatible echo suppressor designed for terrestrial and satellite communications circuits. Operation is provided over circuits with round trip delays of up to 600 milliseconds. The 931C will operate end-to-end with Western Electric's 3A and other CCITT compatible echo suppressors. Flexible automatic disabling is provided as an option.

Type No: 5530A/5540A/5533A Four-Wire Terminating Units

General Descriptive Publication: Form GTEP 342-554-110
(Includes engineering, installation and maintenance information.)

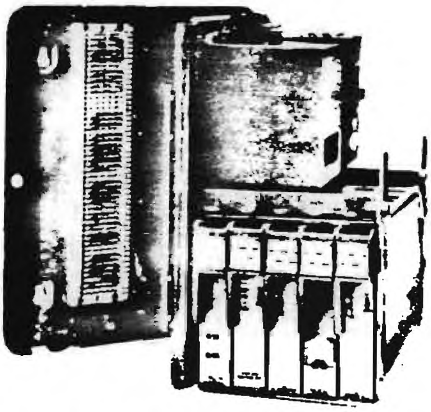
These units provide high-quality conversion of a four-wire circuit to a two-wire circuit, meeting 600 or 900 ohm intertoll switching requirements, and including A, B, D, F, and G leads. The 5540A unit includes switch-selectable attenuation pads and mounts in a shelf 14-inches deep. The 5530A, which does not have the pads, mounts in a shelf 12-inches deep. The 5533A provides a precision balance network for balancing the coil hybrid of a 4-wire terminating set. Networks are available for H88 and D66 loaded cable and non-loaded cable.

Type No: 26600 Signaling Test Set

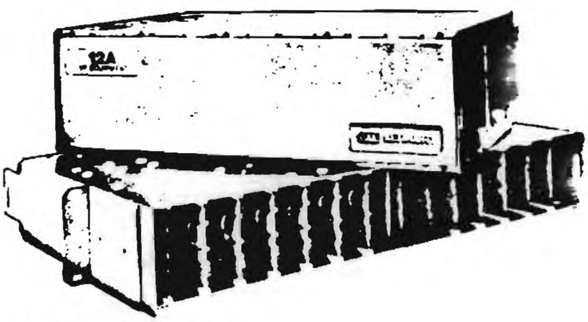
General Descriptive Publication: Form 26600-PS

The 26600 Signaling Test Set is a compact portable or rack-mounted test instrument for checking and monitoring both E&M signaling and loop-dial facilities, either physical or carrier-derived. The 26600 provides such facilities as controlled pulse generation, measurement of pulse speed and ratio, and supervisory lamps for busy circuit monitoring.

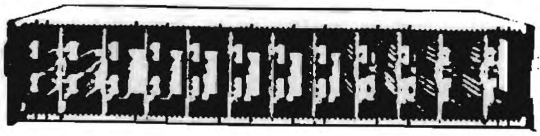
Typical 11A Common Channel Signaling System (CCSS)



111A Special Service Station Assy.
(Cover Removed)
Equipped With One Circuit and Optional
−48/−24 Vdc Converter and 30 Hz Ringing Supply

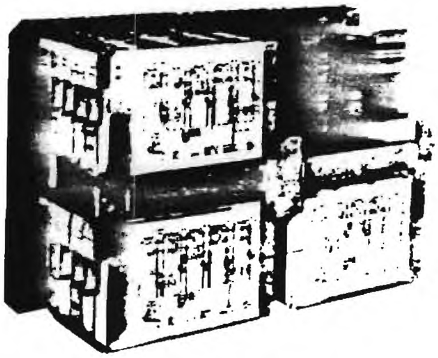


12A VF Equipment

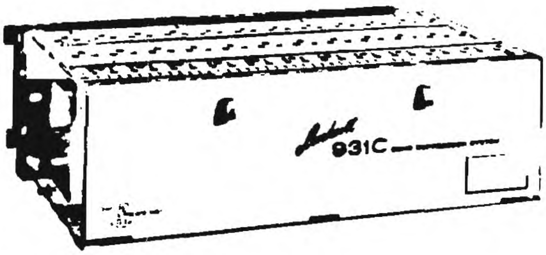


5540A Four-Wire Terminating Shelf Assy.
Equipped With 12 Units

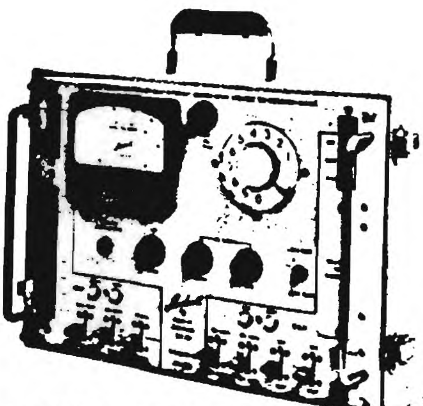
Typical 11A Special Service Station
Equipment Shelf Assy. (1197B)
Equipped with 12 Units



111B Special Service Station Assy.
(Cover Removed)
Equipped with Three Circuits and Optional
−48/−24 Vdc Converter and 30 Hz Ringing Supply



931C Echo Suppressor Assy.
Equipped With 12 Two-Way Echo Suppressors



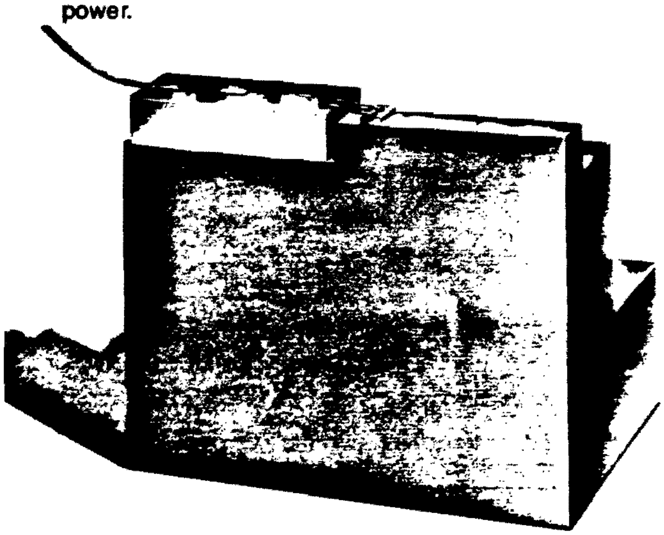
26600 Signaling Test Set

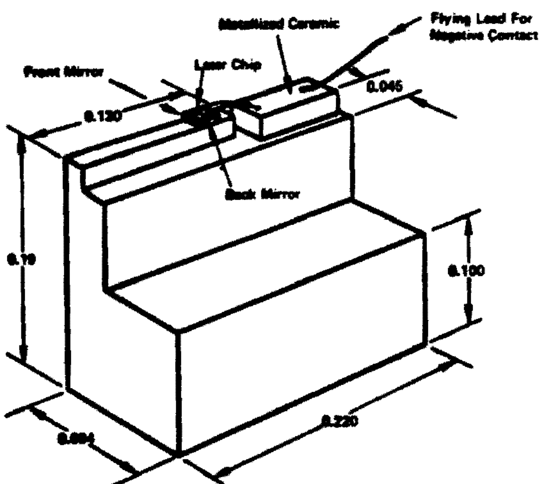
general optronics

semiconductor laser products

CW laser diodes

Intended for the OEM designer who wants to incorporate his own packaging and electronics, the GOLS Series laser diodes are mounted on a specially designed heat sink which permits access to both mirror facets. Unique structural and fabrication technology provides for extremely stable optical waveguides, single transverse modes, low thresholds, high quantum efficiency and high linearity. The GOLS diodes may be operated in the ordinary ambient. No hermetic seals are required. These devices are used in such applications as analogue and digital CATV fiber optic transmission, fiber optic telephone transmission systems, high speed computer data links, non-impact printers, alignment monitor systems, electronic distance measuring systems, and optical scanning systems. Each diode is warranted for 10^4 hours with projections to 100,000 hours of operation at full output power.





Dimensions are in inches

GOLS series

COMMON CHARACTERISTICS

ELECTRICAL

Operating Foreward Voltage .... 1.5 volts to 2.0 volts
Threshold Current at 25°C .... *Typical* 90-110mA
Series Resistance .... 2 Ohms
Modulation Bandwidth .... Better than 1.5 GHz
Operating Temperature .... −50°C to +70°C

OPTICAL

Recommended CW operating power for maximum reliability 5mW
Risetime .... Less than .7 nanoseconds
Wavelength ... 830 nm standard 800-870 by special order
Spectral Width (50% pt) .... Less than 1 nm
Beam Divergence .... 45° Vertical 10° Horizontal
Differential Quantum Efficiency .... Typical 40%
Harmonic Distortion........ Less than 40dB 2nd harmonic and less than 50dB 3rd harmonic at 70% modulation depth
Mode Pattern .... Single Transverse Mode

MECHANICAL

Heat Sink Structure .... Specially designed for easy access to both mirrors (see drawing)
Storage Temperature Range .... −55° to 100°C
Mirror Coating .... Dielectric layer passivation for normal ambient operation
Electrical Connection .... Positive—Heat sink Negative—Gold flying lead

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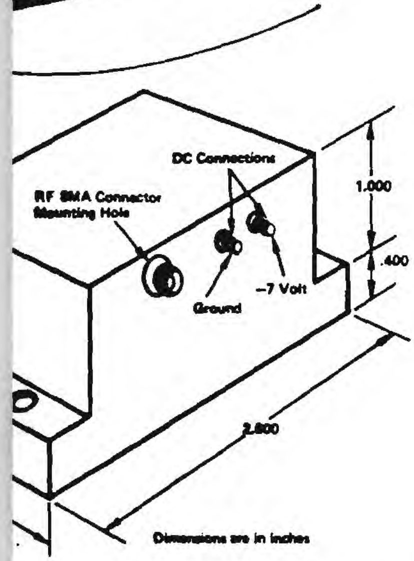
al
nunication
mitters

ıvide the fiber optics systems de-
tate-of-the-art in laser transmitters,
ics Laser Transmitters* feature the
ser diode as its light source. As
nent, the transmitter includes cir-
ation of optical output and transient
. The unit can be pigtailed with any
ed fiber, and may be ordered with a
cooler. GOLT transmitters are cur-
both analog and digital transmis-
cluding those with 13 channels of
ransmission per fiber; telephone
stems as high as T4 rates; high-
r data links; secure military and
munications links; high radiation
mmunications; and security sys-
te in systems design convenience,
s Transmitter carries the General
nty.



GOLT
series

COMMON CHARACTERISTICS

ELECTRICAL

Power Supply .... −7 Volts DC
Total Package Current .... Less than 200mA
Input Impedance .. 50 Ohms, 75 Ohms or by specification
Transient Protection................ Specially designed protective circuitry

OPTICAL

Light Source .... See GOLS series for specifications
Operating CW power .... Adjustable and stabilized by a special optical feedback circuit
Operating Optical Power Stability .... Better than 0.2% at a given temperature; better than 3% over entire operating temperature range

MECHANICAL

Case Dimensions .... See mechanical drawing and chart
DC Input Terminals .... Solder terminals
RF Input Connector .... SMA
Case Material .... Anodized Aluminum
Weight .... Less than 5 ozs.
Storage Temperature ....−50°C to 100°C

OPTIONS

THERMAL ELECTRIC COOLER

Maximum cooling temperature 40° below case temperature
Maximum current .... 1 Amp
Maximum Power Consumption .... 7 Watts
Operating Laser Temperature .... Adjustable (Factory set at 25°C)
Operating Case Temperature ....−40°C to 65°C

MODULATION MODE—ANALOG

Bias Power ...... Adjustable (Factory set at 3 mW/facet)
RF Input .... Less than 20 mA peak to peak for 80% modulation depth
Harmonic Distortion ... Less than 40dB second harmonic; less than 50dB third harmonic; at 70% modulation depth
Bandwidth .... Better than 1 GHz

MODULATION MODE—DIGITAL

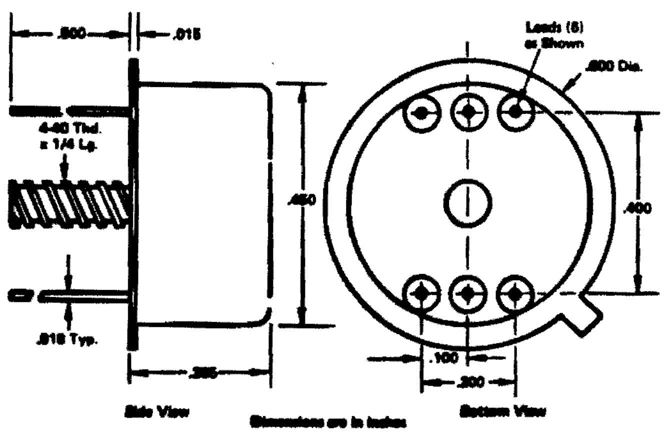
Bias Power .... Adjustable (factory set at near threshold value)
Digital Data Rate .... DC−500 Mbts/Second
Input Format .... NRZ or RTZ
Input Levels .... TTL, ECL (or any other standard logic schemes)
Error Rate .... Less than 10^{-9}

FIBER PIGTAIL

Fiber Type—Standard ...... ITT T-203 graded index fiber NA:0.25 core diameter 55μm attenuation 5dB/km intermodal dispersion 3.5 nanosecond/km
Fibertype—Custom ...... Any fiber supplied by customer
Fiber Preparation .... Micro lens at the source end
Coupling Efficiency .... Typically 50% for our standard fiber pigtail
Percentage of light coupled into the cladding layer. . .less than 0.5% for our standard fiber pigtail

optical instrument light sources

The GOLH Series of optical instrument light sources offers the instrument designer, working with conventional optics, the General Optronics GOLS Series of CW laser diodes packaged in a TO-8 housing. The GOLH may be ordered with optional optical stabilization circuitry, which includes bias point adjustment capability. A sapphire window also may be specified in place of the ordinary glass window. The series is designed to replace He-Ne lasers in certain optical instruments, as well as in other instruments utilizing a bright light source. The applications include line-of-sight transmission, distance measurement, scanners, non-impact printers and alignment monitoring. The GOLH Series devices also carries General Optronics warranty.



GOLH series

COMMON CHARACTERISTICS

Light Source Specifications .. See GOLS for specifications
Package .... Modified TO-8 with six leads
Passivation .... Hermetically sealec
Window Material .... Glass

OPTIONS

PHOTO DETECTOR FOR OPTICAL FEEDBACK

Photodetector (for customer designed optical feedbacl circuits) Large area P.I.N. photovaltaic type supplied witl floating output leads.

HYBRID OPTICAL STABILIZATION CIRCUIT

Total Package Current .... Less than 200 m,
Circuit .... Optical feedback for power stabilizatio
Operating Power .... Adjustabl
Power Stability .... Better than 1°
Modulation Capability .... Up to 15 MH
DC Input Voltage .... −5 Volt
Input Impedance .... Hig
RF Input .... 50 m

WINDOW

Materials .... Sapphir
Lead/Pin Arrangement .... See mechanical drawin

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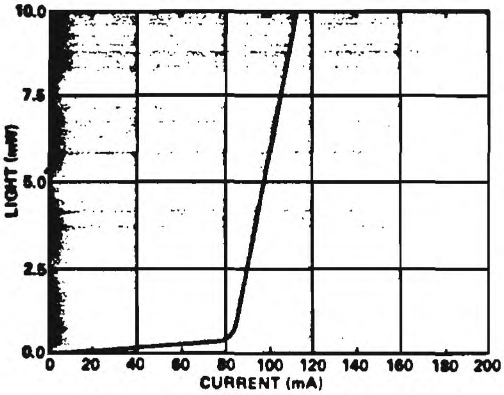
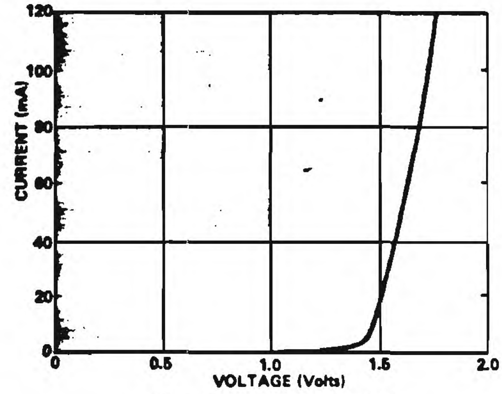
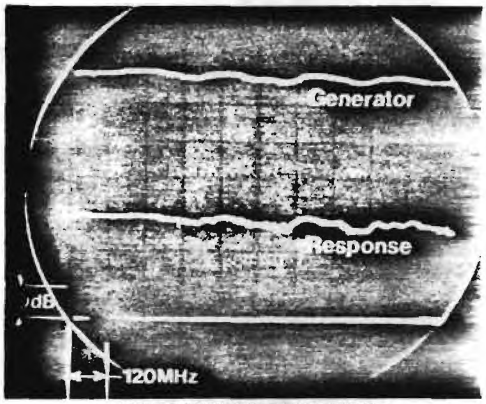
typical performance characteristics



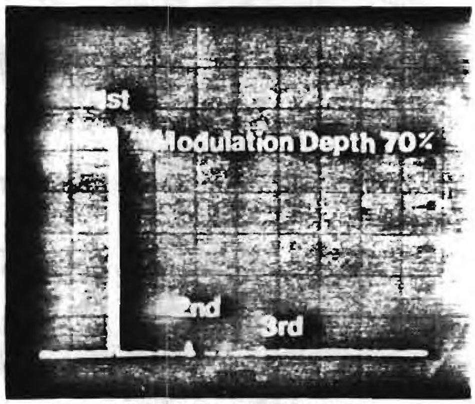
LIGHT OUTPUT CHARACTERISTICS



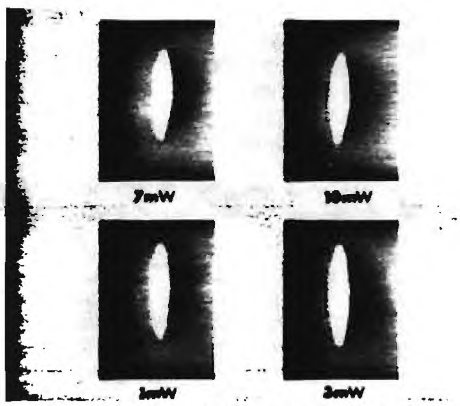
I-V CHARACTERISTICS



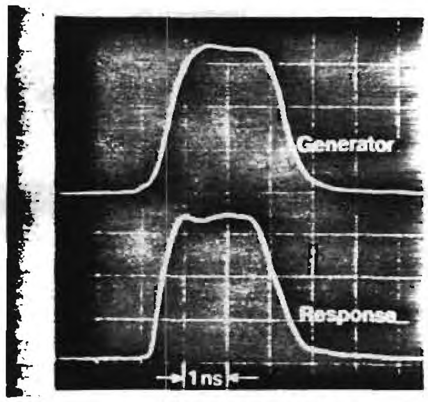
FREQUENCY RESPONSE



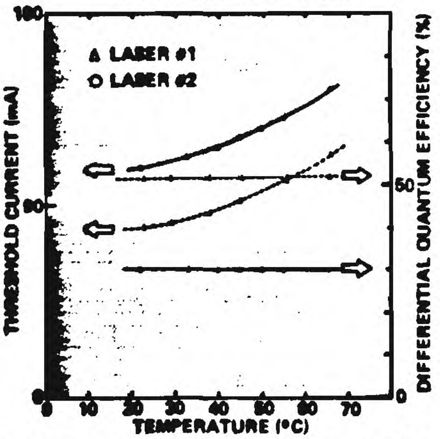
HARMONIC DISTORTION



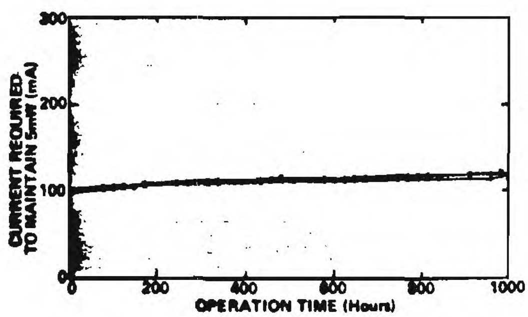
FAR FIELD PATTERNS



PULSE RESPONSE



TEMPERATURE DEPENDENCE OF THRESHOLD AND DIFFERENTIAL QUANTUM EFFICIENCY



LIFE TEST CHARACTERISTICS

ordering information

GOLS series
CW laser diodes

GOLS —	—	
Standard	*Type of Use*	*Wave Length (In nm)*
Specially Designed Heat Sink Flying Lead	**ANA** Analog **DIG** Digital **ILL** Illumination Only **DAA** Digital & Analog	**830** Standard **800*** **850*** **870*** *Available by Special Order

Sample: **GOLS—ANA—830**
Laser Diode For Analog Use With a Standard 830nm wavelength

GOLT series
optical communication transmitters

GOLT —	—	—	—	—	
Standard	*Type of Use*	*Wavelength (In nm)*	*Light Output*	*Thermal Stability*	*I Imp*
Optical Feedback Transient Surge Protection Package Dimensions: 1.410" W 1.400" H 2.600" L	**ANA** Analog **DIG** Digital **ILL** Illumination Only **DAA** Digital & Analog	**830** Standard **800*** **850*** **870*** *Available by special order	**SMF** Single Mode Fiber Pigtail **MMS** Multi-Mode Step Index Fiber Pigtail **MMG** Multi-Mode Graded Index Fiber Pigtail **999** No Fiber Pigtail **CUS** Custom	**TEC** Thermal Electric Cooler **999** No Thermal Electric Cooler	**50** 50 C **75** 75 C **CUS** Cus

Sample: **GOLT—ANA—830—MMG—TEC—50**
Transmitter for Analog Use, with a Standard 830nm wavelength, Multi-Mode Graded Index Fiber Pigtail Light Output, Thermal Electric Cooler and impedance input of 50 ohms.

GOLH series
optical instrument light sources

GOLH —	—	—	—	
Standard	*Type of Use*	*Wave Length (In nm)*	*Interior Circuitry*	*Window Glass*
GOLH Laser Diode TO-8 Package Hermetically Sealed	**ANA** Analog **DIG** Digital **ILL** Illumination Only **DAA** Digital & Analog	**830** Standard **800*** **850*** **870*** *Available by special order	**HYB** Hybrid Optical Feed Back Circuitry **DET** Photo Detector **999** No Hybrid Circuitry	**SAP** Sapphire **GLA** Glass

Sample: **GOLH—ILL—830—HYB—GLA**
Light source for illumination only with standard 830nm wavelength, optical feed back circuitry and glass window

LIMITED WARRANTY

"We provide a limited warranty that our lasers will not fail under normal use during the first 10,000 hours beginning from date of invoice and that the electronic portions of our products will not fail within one (1) year from date of invoice whether used continuously or intermittently. For full details of our limited warranty, see the enclosed warranty sheet."

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ALL-WEATHER MTV SERIES

Portable, High Performance, \ Video Microwave Transmission Link

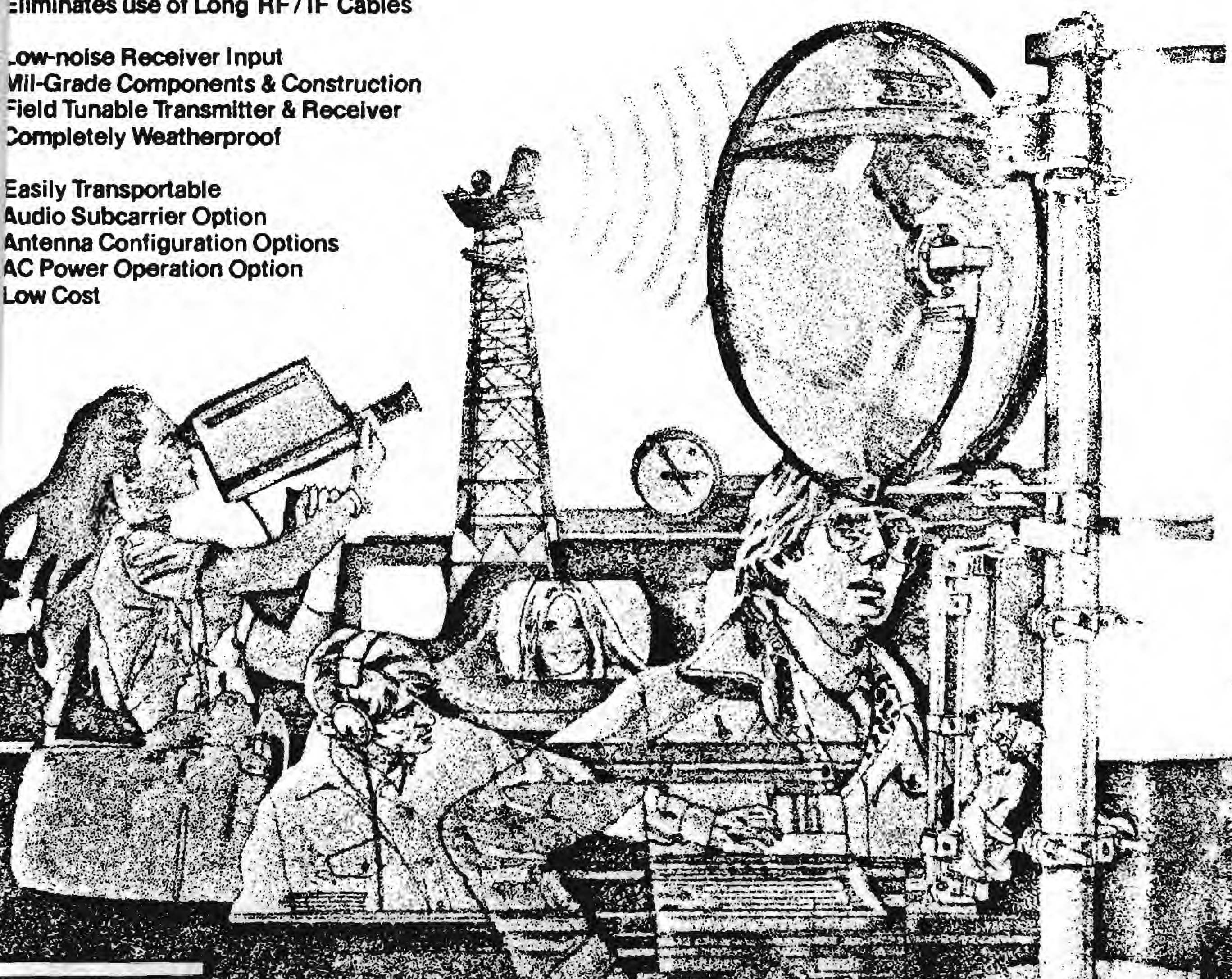
■ Studio to Transmitter Links (STL) ■ Data Communications ■ TV Security Surveillance
■ Military Field Applications ■ Meets EIA, CCIR, & FCC Standards

EATURES

State-of-the-art Performance
RFI/EMI Shielded
Jltra Compact — Rugged Construction
Eliminates use of Long RF/IF Cables

Low-noise Receiver Input
Mil-Grade Components & Construction
Field Tunable Transmitter & Receiver
Completely Weatherproof

Easily Transportable
Audio Subcarrier Option
Antenna Configuration Options
AC Power Operation Option
Low Cost



RHG ELECTRONICS LABORATORY INC

New York 11729 ■ TWX 510-227-

:TABLE, HIGH PERFORMANCE, FM VIDEO
ROWAVE TRANSMISSION LINK
/EATHER MTV SERIES

'EM DESCRIPTION

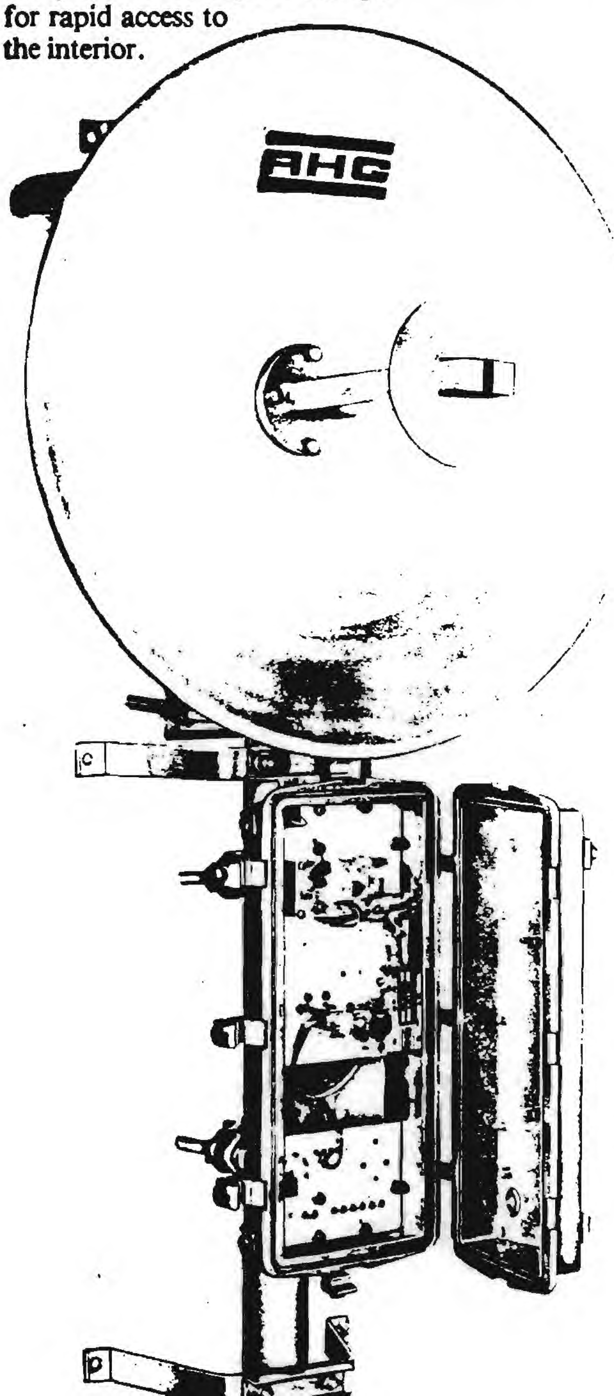
's high quality TV transmissions for both :ast and communications, and the fast pace /hich video information must be sent from :o point, requires a new generation of equip- to meet this need. RHG has combined its edge of microwave link technology and broad experience to produce a new, low cost, high mance, FM microwave TV link designed pri- for outdoor and field applications where reli- ull fidelity performance is of prime importance.

: MTV Series Transmission Link is a compact 1, small enough to be transported in any size : and set up by one person for attended or un- led operation. A full link consists of two an- assemblies, a receiver unit, and a transmitter capable of operation over distances of up to les and greater.

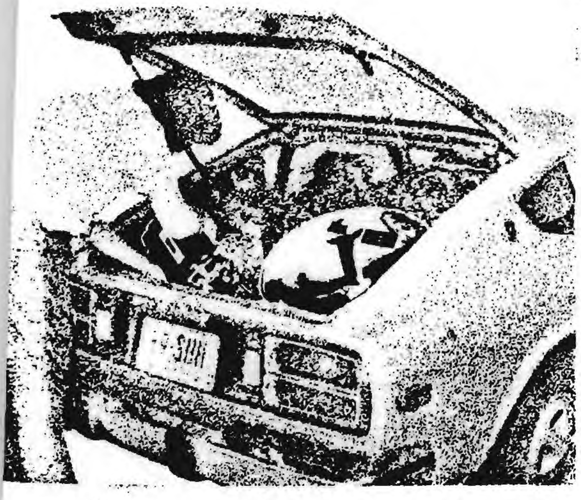
e MTV Series is available in twelve standard special models for operation at frequencies 1 to 15 GHz. . . and there are *no controls or :tments required to achieve rated performance.*

■ Audio subcarriers, special configuration antennas, and operation from virtually any prime power source are available options.

■ The transmitter and receiver units are housed separately in extremely rugged, cast aluminum, fully shielded, weatherproof enclosures complete with easily unlatched captive clamps for rapid access to the interior.



ghtweight MTV System can be easily hand ried and set up for operation by one person.

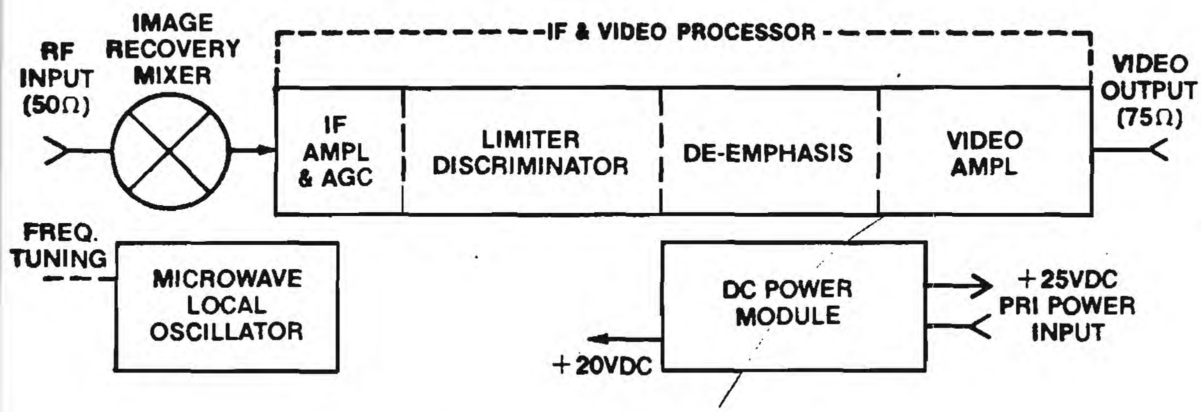


CEIVER DESCRIPTION

F input signal is down converted in an RHG-designed E RECOVERY MIXER (U.S. PATENT #3831097) to le a low noise front-end without the need for a ate low noise preamplifier.
s unique mixer circuit provides for exceptional low performance and results in intermodulation and alk that is typically 40 dB better than receivers using B gain RF preamplifier. The RHG mixer circuit also les image rejection without the use of RF filters.

The **IF & VIDEO PROCESSOR** circuits amplify, demodulate, and provide video processing to produce the required video output. The **MICROWAVE LOCAL OSCILLATOR** is screwdriver adjustable and stabilized to meet the performance requirements over the rated temperature range.

A special **DC POWER MODULE** accepts the raw DC input and produces the necessary voltage needed for proper receiver operation.

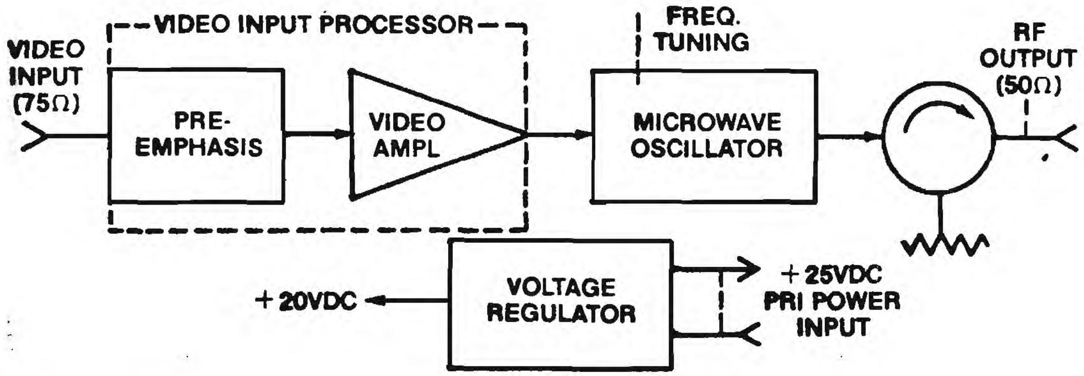


ANSMITTER DESCRIPTION

ransmitter circuit contains a **MICROWAVE OSCIL-R** capable of being frequency-modulated at high and frequency adjusted with a screwdriver adjust-control. The output circuit utilizes a ferrite isolator nimize effects of output load VSWR and protect st open or short-circuited load conditions.

The input video signal is pre-emphasized and amplified in the **VIDEO INPUT PROCESSOR** circuit.

A solid-state **VOLTAGE REGULATOR** conditions the input DC voltage to provide a regulated +20VDC for the microwave source.



RHG ELECTRONICS LABORATORY·INC

161 East Industry Court ■ Deer Park, New York 11729 ■ (516) 242-1100 ■ TWX 510-227-6083

CIFICATIONS

MTV SYSTEM

RF Frequency:	See table below
Baseband Response:	10 Hz to 6 MHz, less than 2% tilt on 60 Hz square wave
Video Impedance Level:	75 ohms
RF Impedance Level:	50 ohms
Modulation Type:	FM (8 MHz p-p deviation)
Pre/De-emphasis:	525 line per CCIR Rec 405 Curve B
Differential Gain:	0.5 dB (typical) at 10%, 50%, and 90% APL
Differential Phase:	± 1.0° (typical) at 10%, 50%, and 90% APL
Signal-to-Noise A Weighted at − 40 dBm):	60 dB
al-to-Hum (EIA Weighted):	56 dB

RECEIVER

RF Input Impedance:	50 ohms
Noise Figure:	See table below
Image Rejection:	Greater than 20 dB (not appl. on MTV 12.4 models)
Video Outputs:	One
Video Output Level:	1 V p-p for rated transmitter input of 1 V p-p
Video Output Impedance:	75 ohms
Carrier Level Indication:	For antenna alignment, an AGC voltage sample is brought out in the diagnostic power connector
Weight:	18 lbs. (typical)

TRANSMITTER

Output Power:	See table below
RF Output Impedance:	50 ohms
Modulation Sensitivity:	1 V p-p for rated deviation
Video Input Impedance:	75 ohms
Stability:	± 0.05% (± .005% on MTV 12.4 HP)
Weight:	15 lbs. (typical)

GENERAL

Prime Power Input:	+ 23 to + 28 VDC at 0.5A for standard transmitter (nominal); at 0.8A for HP transmitter (nominal); at 0.8A for receiver (nominal). AC power options available, see options available section.
Temperature:	− 30 °C to + 55 °C
Connectors:	Type "N"
General Environment:	Designed for unprotected outdoor usage. Case is fully weatherproof and RFI shielded.
Power Connector:	Multi-pin, screw-on (mate supplied)
Diagnostic Connector:	A series of built-in outputs are brought out to a diagnostic connector.

MTV SERIES MODEL SPECIFICATIONS

System Performance w/ Std 2 ft Dishes (assuming clear line of sight)

System lodel No. (note 1)	Freq Range (GHz) (note 2 & note 4)	Transmit Power dBm	Receiver Noise Figure dB	1 MILE Rec'd. Level dBm	1 MILE *Fade Margin dB	2 MILES Rec'd. Level dBm	2 MILES *Fade Margin dB	5 MILES Rec'd. Level dBm	5 MILES *Fade Margin dB	10 MILES Rec'd. Level dBm	10 MILES *Fade Margin dB
TV-1.7 TV-1.7HP	1.5 to 1.9 GHz	+17 +27	4.5	−49 −39	29 39	−55 −45	23 33	−63 −53	15 25	−69 −59	9 19
TV-2.0 TV-2.0HP	1.9 to 2.2 GHz	+17 +27	4.5	−47 −37	31 41	−53 −43	25 35	−61 −51	17 27	−67 −57	11 21
TV-4.7 TV-4.7HP	4.4 to 5.0 GHz	+ 17 +27	5.0	−40 −30	38 48	−46 −36	32 42	−54 −44	24 34	−60 −50	18 28
TV-7.0 TV-7.0HP	6.8 to 7.2 GHz	+ 16 + 26	5.5	−38 −28	40 50	−44 −34	34 44	−52 −42	26 36	−58 −48	20 30
TV-7.7 TV-7.7HP	7.1 to 8.4 GHz	+ 13 + 23	5.9	−40 −30	37 47	−46 −36	31 41	−54 −44	23 33	−60 −50	17 27
TV-12.4HP	12.7 GHz	+ 17	7.5 (note 5)	−32	43	−38	37	−46	29	−52	23

ES:

system consists of one transmitter, one receiver and two 2 ft. antenna assemblies.

requencies are preset at factory. Frequency is readily changed by ser: up to 5% range on standard models; up to 2% range on HP odels.

***3. Fade Margin referenced to a 40 dB video S/N ratio which reflects a typical high quality video presentation.**

4. Any frequency from 150 MHz to 15 GHz can be provided on special order.

5. Uses special low noise double balanced mixer.

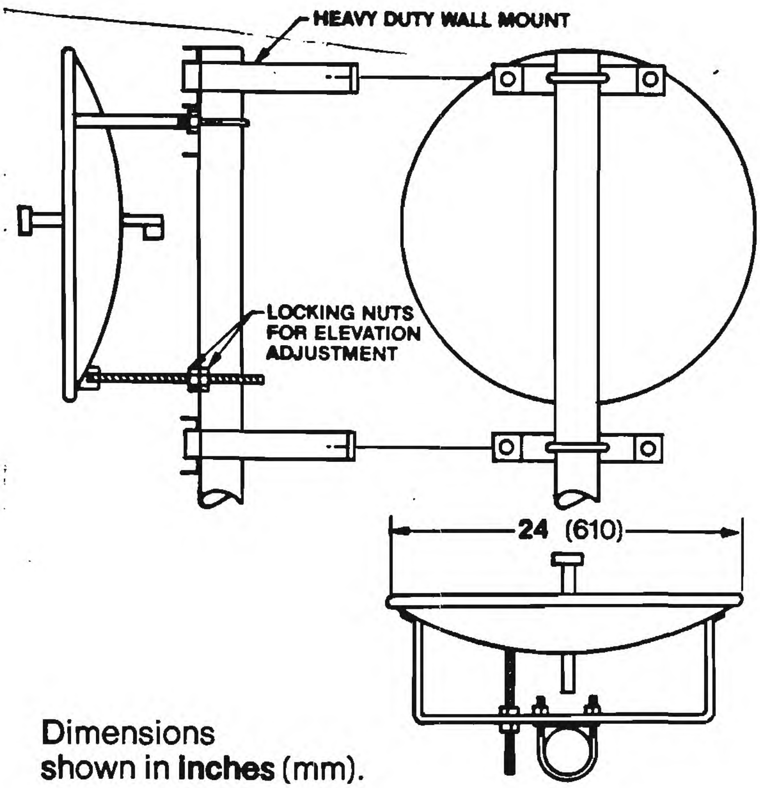
ꟷIENSIONAL DATA

ꟷNNAS

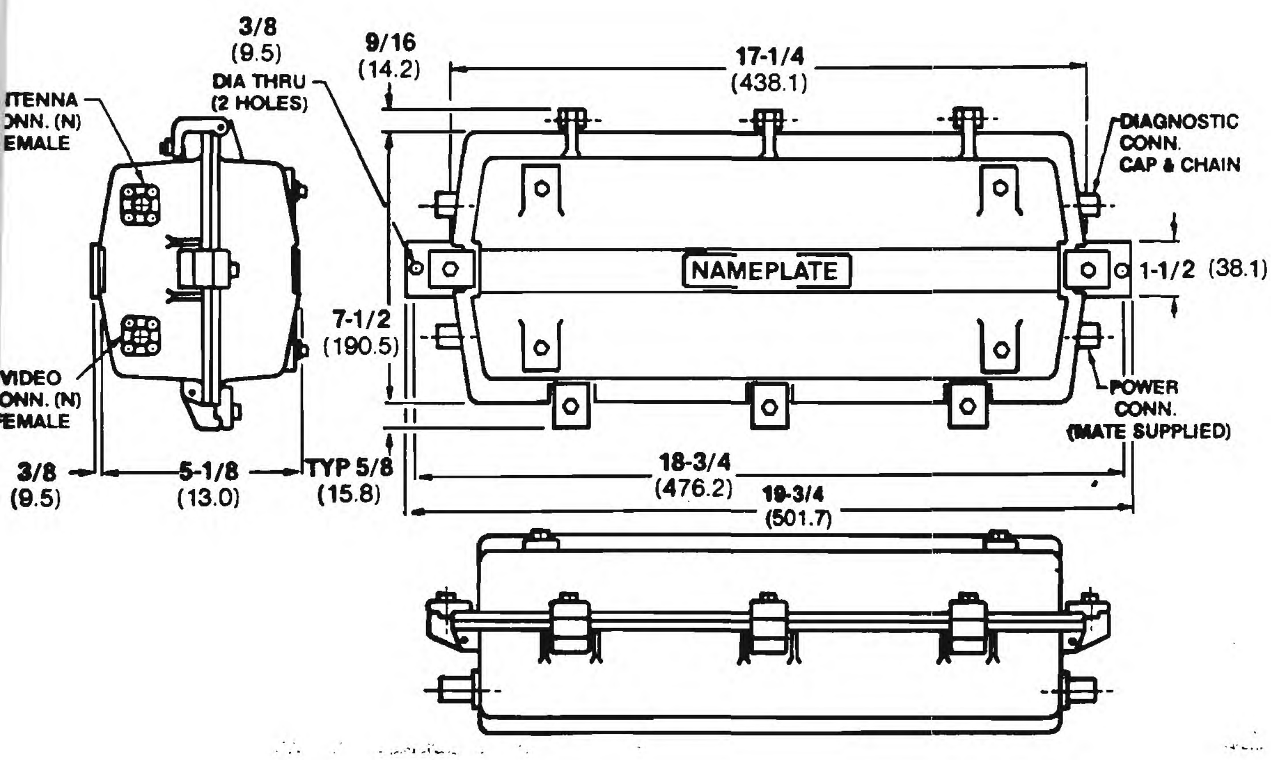
ꟷandard MTV System is supplied
ꟷo 2-foot antennas with associated
ꟷire suitable for mounting the
ꟷcomponents to a 2-1/2-inch pipe.
ꟷzimuth and elevation adjustments
ꟷily accomplished because of the
ꟷeight of the assembly. Alternate
ꟷa configurations such as horns,
ꟷand large dishes up to 6 feet in
ꟷer, are optionally available.

ꟷISMITTER & RECEIVER

ꟷnsmitter and receiver units are
ꟷd in rugged, fully-shielded, cast
ꟷium, weatherproof enclosures
ꟷasily unlatched captive clamps for
ꟷaccess to the interior. The housings
ꟷsily mountable to any size pipe, up
ꟷ2 inches in diameter, or to a flat
ꟷe with the mounting bracket
ꟷed.



Dimensions shown in **inches** (mm).



V SERIES OPTIONS

Subcarrier Channel: (Option ASCX7.5)
es a high fidelity audio channel capability with a cy response of 50 Hz to 15 kHz, input/output of +9 dBm and a subcarrier frequency of 7.5 leviation 280 kHz p-p).

wer Supply: (Option ACP-25)
es the added capability of AC line operation in ons where AC power is available and/or desired. ging is completely weatherproof and no controls ustments are required. The ACP-25 accepts 115 or AC, 47 to 60 Hz input and provides a +25 VDC at) output, suitable for any combination of two receivers/transmitters. It is ruggedly packaged in a 6" x 6" x 8" waterproof housing and is capable of operation at temperatures of −30°C to +55°C. Specify 115 or 230 V when ordering.

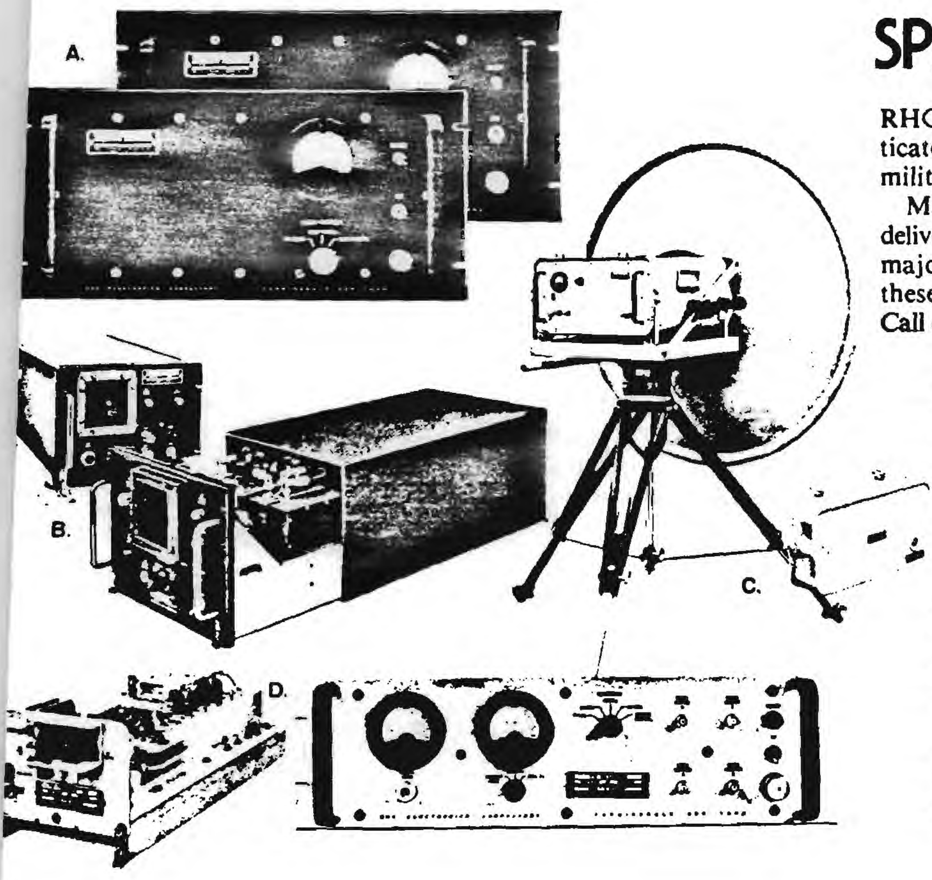
Unattended Power Sources
For those locations where unattended operation is desired, special power sources using solar panels, fuel cells, and gas generators can be provided. RHG application engineers can advise and assist in the selection of special power sources.

Antenna Assemblies
A complete range of antenna units up to 6 feet in diameter can be supplied on special order. In addition, horn devices, yagi devices, and other special configurations are available. Contact RHG application engineers for assistance.

V TO ORDER AN MTV SYSTEM

lard MTV System: To order a standard MTV System sting of two antenna assemblies, one receiver, ne transmitter, simply select the desired frequency eration and add this as a suffix following the l number: i.e., MTV-12.4/12.7125

Ordering Options: To order available options, select from the Options Available listing and state the option model number alongside the MTV System model. If assistance is required, please contact RHG application engineering department.



SPECIAL SYSTEMS

RHG manufacturers highly sophisticated Microwave Relay Links for military and industrial applications.

Many of these links have been delivered to the U.S. Government and major broadcast networks. A few of these special models are illustrated. Call or write for technical information.

A. Point to Point (C-Band)—High Shock Environment. Low intermodulation. High Signal-to-Noise. Diplexed Operation.

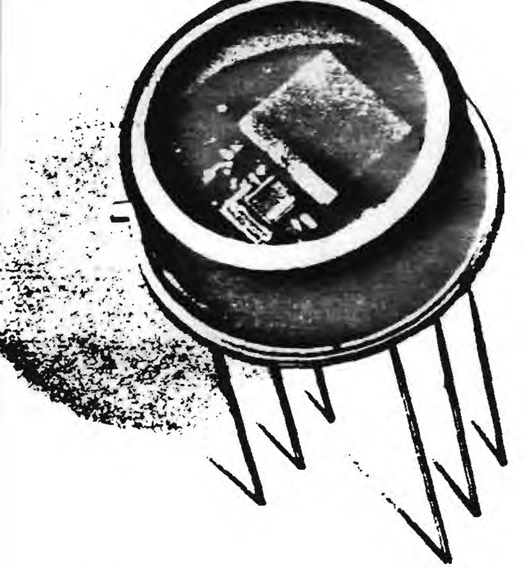
B. Air to Air (L, S, C, X-Bands)—Very Wide-band. Meets MIL-E-5400. RFI Protected. 200 Nautical Mile Range.

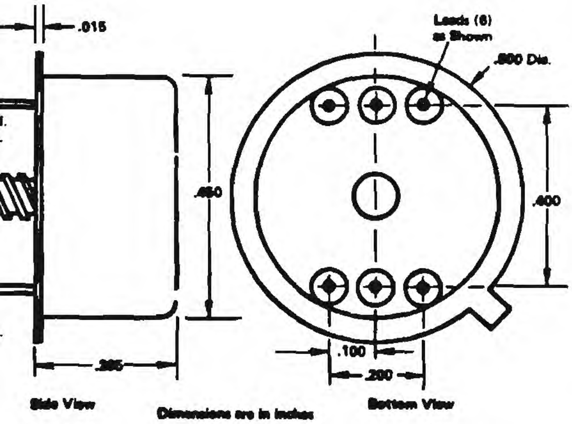
C. Ground Stations (2 thru 13GHz)—Portable or Fixed Installations. Rugged—Weatherproof. Built-in Subcarriers. Meets EIA, CIR, and FCC Standards.

D. Air to Ground (9GHz)—1000 Line Resolution Missile Grade Transmitter. AFC Frequency Control. Switchable Receiver Bandwidths.

ptical
ıstrument
ght sources

GOLH Series of optical instrument light 'ces offers the instrument designer, working conventional optics, the General Optronics .S Series of CW laser diodes packaged in a 8 housing. The GOLH may be ordered with ɔnal optical stabilization circuitry, which in- es bias point adjustment capability. A sapphire low also may be specified in place of the ordi- ' glass window. The series is designed to re- e He-Ne lasers in certain optical instruments, vell as in other instruments utilizing a bright light rce. The applications include line-of-sight smission, distance measurement, scanners, -impact printers and alignment monitoring. The LH Series devices also carries General ronics warranty.





GOLH series

COMMON CHARACTERISTICS

Light Source Specifications	See GOLS for specifications
Package	Modified TO-8 with six leads
Passivation	Hermetically sealed
Window Material	Glass

OPTIONS

PHOTO DETECTOR FOR OPTICAL FEEDBACK

Photodetector (for customer designed optical feedback circuits) Large area P.I.N. photovaltaic type supplied with floating output leads.

HYBRID OPTICAL STABILIZATION CIRCUIT

Total Package Current	Less than 200 mA
Circuit	Optical feedback for power stabilization
Operating Power	Adjustable
Power Stability	Better than 1%
Modulation Capability	Up to 15 MHz
DC Input Voltage	−5 Volts
Input Impedance	High
RF Input	50 mV

WINDOW

Materials	Sapphire
Lead/Pin Arrangement	See mechanical drawing

general optronics corp.

General Optronics Corp. • 3005 Hadley Road, South Plainfield, NJ 07080 • Tel. 201-753-6700 • TWX 710-997-9556

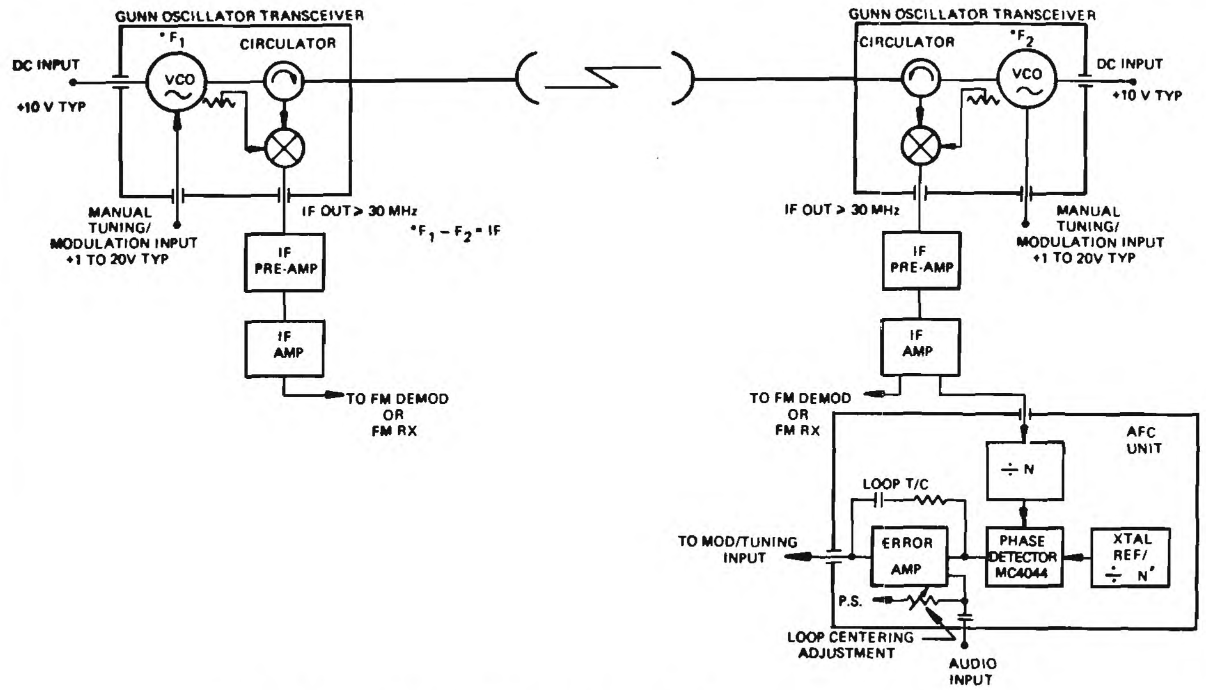


FIGURE 1 ONE POSSIBLE METHOD OF APPLYING AFC (DIGITAL)

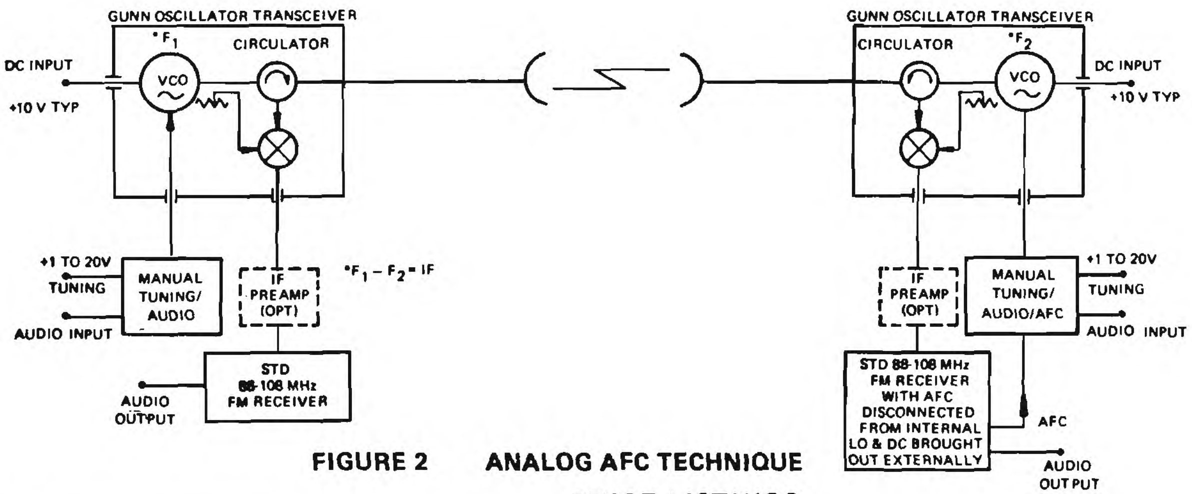


FIGURE 2 ANALOG AFC TECHNIQUE

PRICE LISTINGS

Model	Description	Unit Price
MA-87108-1	Gunn Oscillator and Tuning Varactor	$ 60
MA-87127-1	Complete Transceiver	$ 85
MA-87127-2		$135
MA-87127-3		$170
MA-87140-1	Complete Transceiver and Antenna	$108
MA-87140-2		$158
MA-87140-3		$193
MA-87141-1	2-Complete Transceivers and Antennas	$180
MA-87141-2		$285
MA-87141-3		$370

Prices are F.O.B. Burlington, MA.
Discounts available for quantity orders above 100 pieces.

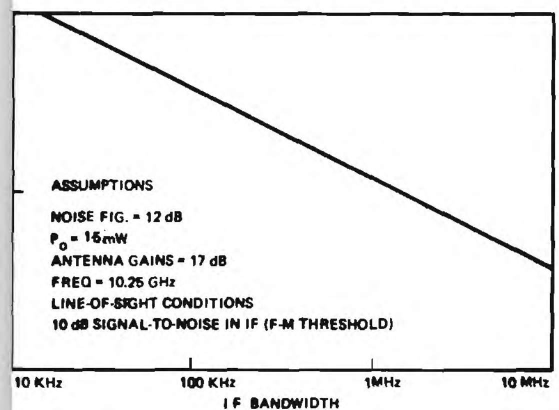
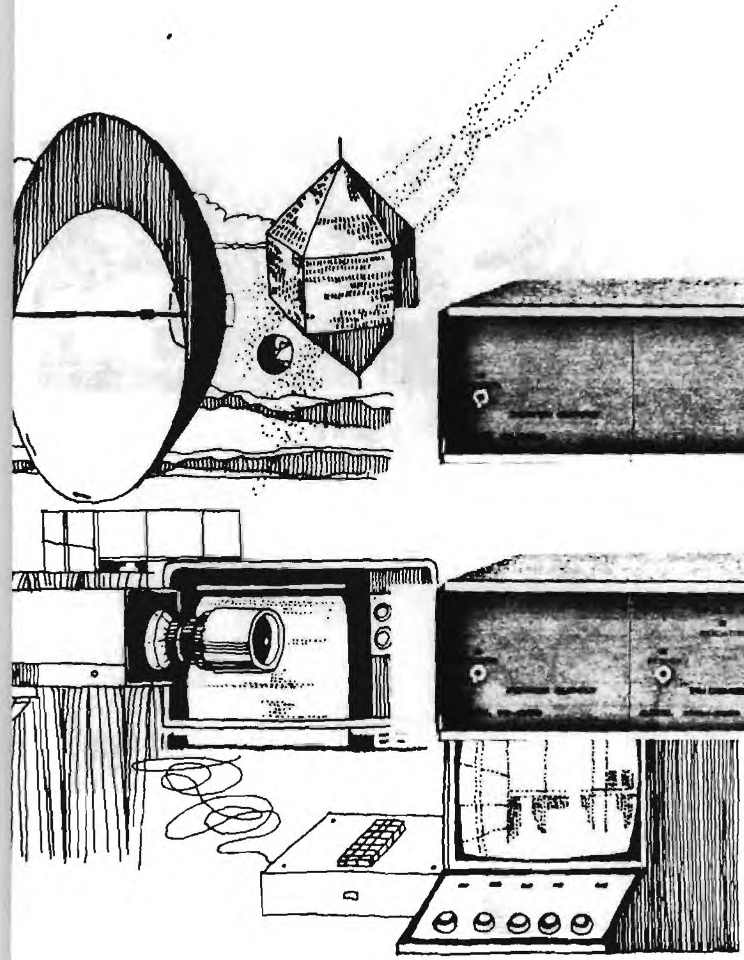


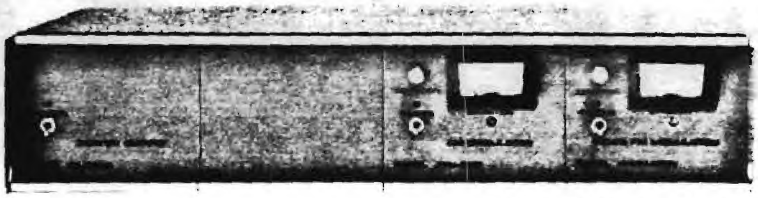
FIGURE 3

UNITED KINGDOM
Microwave Associates, Ltd.
Dunstable LU 6-45X
Bedfordshire
England
Tel. DUNSTABLE (0582) 601441
TELEX 82295
CABLE - MICROWAVE DUNSTABLE

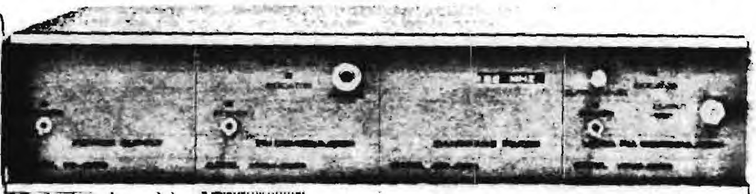
CATEL

VFMS 2000 SYSTEM





VFMM Video FM Modulator
with Audio Module



VFMD Video FM Demodulator
with Audio Module

deo/FM Coaxial Cable Transmission System

JRES:

- than 60 dB Signal to Noise
- ed Impulse Noise Immunity
- Transmission Runs with Less Distortion
- n and Tilt Compensation Required
- aintenance, Solid State Design
- um Cross-Modulation Effect
- utput Levels
- ed Group Delay Performance
- or PCM Multiplex
- Cost than Comparable AM Systems
- um Effect from Intruded Signals

DESCRIPTION

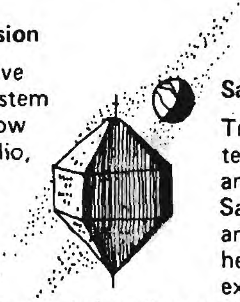
The Catel VFMS Video FM Transmission System consists of a VFMM-2000 Video FM Modulator and a VFMD-2000 FM Video Demodulator. Frequency range available is from 19 to 293 MHz with standard bandwidth of 14 MHz. (Special bandwidths optional)

Due to the noise immunity advantages inherent in FM, this system is capable of long distance transmission of high speed data, television pictures or facsimile with minimum distortion.

Open Up a Broad Area of Applications

Long Trunk Signal Transmission

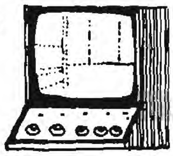
As an adjunct or an alternative to microwave, the VFMS System can provide a high quality, low cost method of trunking audio, video and data over terrain where line-of-sight path and noise problems effect both
my and signal quality. It also offers a
and transmission option where micro-
:hannels are not available, or provides
l feeder system for microwave,
te and other wideband systems.



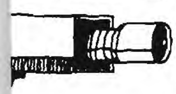
Satellite Terminal Access

Transmission of pay television programming and other services from Satellite terminals to and from the system head end requires the exceptionally clean transmission characteristics of FM. Redistribution with minimum distortion and minimum requirement for amplifiers and special power sources makes the VFMS-2000 system ideal for this application.

2-Way videophone Teleconferencing

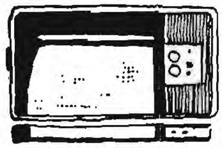


Teleconferencing systems using multiplexed carriers gain significant improvements with FM. VFMS provides long transmission runs with higher quality pictures than are obtainable using broadband video or AM systems.



Television Surveillance

Due to the straight-forward design characteristics of VFMS-2000, the transmission cost of surveillance systems is considerably lower from a purchase as well as a maintenance standpoint as compared to a conventional AM system. It also has the added advantage of noise immunity for installations close to industrial, medical and vehicular noise sources.



Facsimile and Data Transmission

Facsimile and high speed data transmission, where high signal accuracy is required, is ideally suited for the VFMS-2000. Again, the noise-free and improved group delay characteristics of FM ensures low error transmission. (Preliminary tests in an active CATV system show error rates as low as approximately 2 errors in 10^{-11} with Pulse Code Modulation-PCM-TI.)

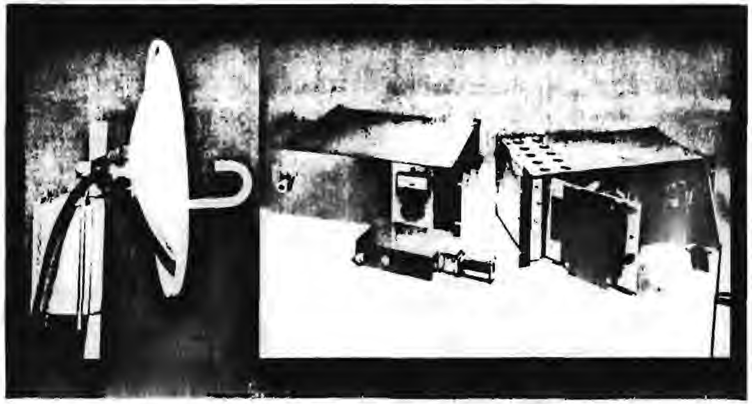
DEMODULATOR				MODULATOR/ DEMODULATOR[1]	
Video 19-33 MHz	Video 34-293 MHz	Video/Audio 19-33 MHz	Video/Audio 34-293 MHz	Two-way Mod. 19-33 MHz Demod. 34-293 MHz	Two-way Mod. 34-293 MHz Demod. 19-33 MHz
XX	XXX	XXX	XXX	XXX[3]	XXX[3]
XX	XXX	XXX	XXX	XXX[5]	XXX[5]
				XXX	XXX
XX	XXX	XXX	XXX	XXX	XXX
				XXX	
:XX	XXX	XXX	XXX	XXX	XXX
				XXX	XXX
		XXX	XXX	XXX	XXX
:XX	XXX			XXX[4]	XXX

COMMUNICATIONS SYSTEMS

ICM Microwave Communications products represent the latest state of the art, technological advances in point to point communications systems. Years of experience in all types of microwave systems — high density, low density, long haul systems, and short haul systems, video, voice and data applications — have gone into the design of these products. These advances combined with International Microwave "Know-How" provide *for reliability, versatility, and quality service for many years to come.*

Features ▪ Benefits

- **Solid State Dependability** — The 100% solid state design features no tubes in either the transmitter or receiver. This means top reliability, instant power, less heat, less maintenance and assures you the reliability required to meet applications where consistent communications are essential.
- **Tower or Rack Mounted** — To meet your exact requirements and insure system integrity all International Microwave systems are available in the "Traditional" 19" E.I.A. rack mounted configuration, or the **"Pole Mounted"** tower configurations. The 19" rack mount allows you to install the transmitter and receiver with existing rack mounted equipment. The revolutionary **"Pole Mounted"** tower configuration installation allows for the installation of the transmitter and receiver on your pole or tower right next to the parabolic antenna. This eliminates costly wave guide transmission systems completely, no dehydrators are needed. The large amount of power normally lost in the wave guide transmission system is now completely utilized in the microwave transmission system thus assuring you of better gain, minimal losses and excellent system performance.
- **Rugged Design** — The latest technological advances and dependable solid state performance match the construction of the design equipment. Transmitter and receiver are enclosed in heavy-gauge steel for maximum protection of components from dirt, dust and splashing water, and rough duty. In addition the **"Pole Mounted"** tower versions are completely weather proof and immune from the elements. Extra heavy circuit boards are eyletted at each connection point to provide the strongest possible solder joints. The finest components available today in the industry are mounted close to the boards to resist vibration and bending.



- **Transmitter Output** — The solid state modular constructed transmitter can take the heaviest duty cycle possible — 100% transmit duty cycle at rated power output. Combine this continuous duty feature with the proven high technology design, and you have the ultimate in transmitter dependability, minimal fades and complete system integrity.
- **Modular Construction** — State of the art design protects the microwave links from obsolescence for many years to come. In the event of a technical improvement or modification, simply by replacing that circuit board you can take advantage of that improvement and update your system, modular construction also allows for easy serviceability by allowing the technician to isolate the trouble spot and keep any down time to an absolute minimum.

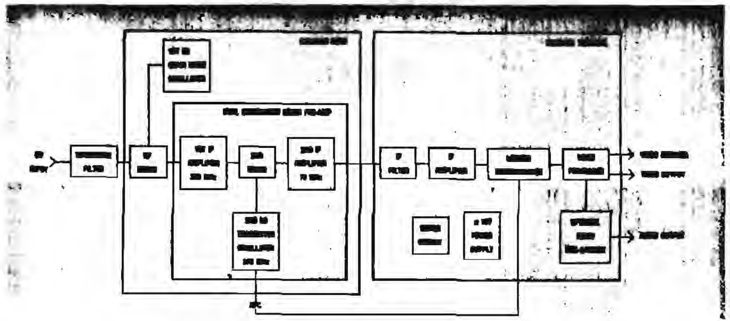
Options ▪ Models

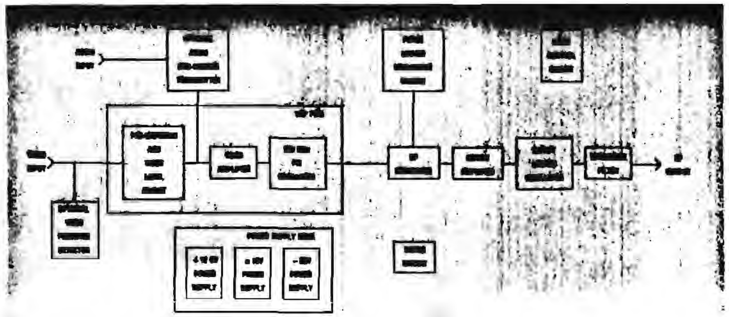
- **Primary Power Flexibility** — Standard primary power is 117 V.A.C.. To tailor the system to your requirements other primary power options are available:

12 V.	DC Operation
24 V.	DC Operation
48 V.	DC Operation
220 V./50HZ	AC Operation
*117 V./12 V.	AC/DC Operation

*117 V./12 V. DC operation with charger, system reverts from 117 V.A.C. to 12 V. DC power upon loss of electrical service, charger keeps battery fully charged for those "Emergencies"

- **Subcarriers** — Maximum utilization of your system is achieved with the addition of audio, program or data subcarriers for the timely and simultaneous transmission of voice and data. An additional option provides for the mounting of up to 5 subcarriers in a 19" equipment mounting rack.
- **Multiplexers** — Can be utilized to combine up to 6 channels through one antenna.
- **Order Wire** — Allows for communications between sites by your staff and technical personnel.
- **Alarm Reporting and Control** — A hierarchy of modular alarm systems for centralized alarm reporting and remote control are available as an effective means of monitoring and controlling a microwave communications system whether it be a one hop system or a nationwide telecommunications network. Alarm and control systems are for use in monitoring microwave communications systems and to utilize your system to the fullest extent the alarm systems may be interfaced to provide indications of building intrusion, smoke and fire alarm, equipment malfunctions and proper operation of any other equipment at the site of a microwave communications system.





Block Diagrams

A block diagram of an F.M. system is shown above. Incoming video signals are applied to the transmit terminal where they are pre-emphasized, filtered and attenuated to appropriate levels. Audio signals are converted to an FM subcarrier if the terminal is so equipped. Both the video and audio subcarrier frequency modulate a 250 MHz VHF Oscillator. This signal is fed to the transmitter RF head where it is amplified, then upconverted by mixing with a crystal controlled oscillator source. The signal is now at the final on-the-air frequency, but at a low level. It is applied to a multi-stage impatt amplifier to achieve full power, then filtered and sent to the parabolic antenna for transmission to the receiver. At the receiver, the signal is filtered to reject any possible interference, then down-converted to 300 MHz by mixing with a local oscillator. After first I.F. preamplification, the signal is again down-converted to the dual I.F. frequency, 70 MHz. Dual conversion of this type affords superior image rejection. The 70 MHz signal is sent from the receive terminal where it is filtered, amplified and applied to the FM limiter-discriminator for demodulation. The discriminator output DC voltage is amplified and sent back to the RF head in an AFC loop which locks the receiver frequency. The main discriminator output is deemphasized and split into the video and audio subcarrier signals. The video signal is amplified and presented to the output at an impedance of 75 ohms. The audio signal is demodulated in the subcarrier receiver with an output of 600 ohms balanced line.

Plain Talk On Log Amps

Understanding how the IF log amp relates to other components in a receiving system can clear up many questions surrounding anomalies in measured video output, bandwidth, pulse fidelity, and dynamic range.

THE ubiquitous logarithmic amplifier can be found in the IF sections of rly all radar, ECM, and other receiving systems. But spite of the amplifier's commonality, engineers are tinely misled when they apply linear reasoning to a linear transfer characteristic, and fail to evaluate the act of other components in the system on the per- nance of the log amp.

pparent anomalies in video output level, dynamic range, dwidth, and pulse response can often be traced to roper measurements or assumptions. For example, CW age from a test generator can make a log amp appear ave less dynamic range than it can actually deliver in stem. On the other hand, too much system preamplifier may restrict dynamic range and video output level to than that measured in the lab. Questions of pulse lity are also important. Many designers forget that the lifier's logging action also applies to the leading and ling edges of pulses, not just to their peaks. Even simple s such as evaluating 3-dB bandwidth can be brainteasers a log amp. (Think about it: Is the 3-dB point really 7 times the peak amplitude?)

og amps translate a wide input range to a much narrower ge by using a known logarithmic transfer function. This rs a major advantage over loop-type systems: a wide antaneous dynamic range is available without the limi- on of AGC time constants. A log amplifier typical of y of those used in today's systems might have the wing specifications:

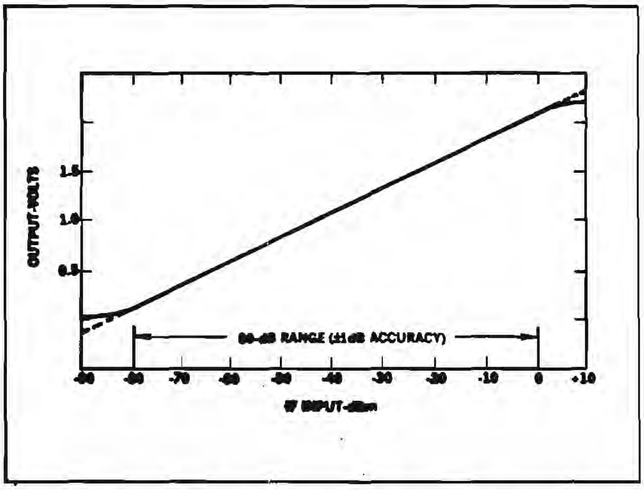
Center frequency/bandwidth	60/20 MHz
Input dynamic range	−80 to 0 dBm
Log accuracy	±1 dB
Rise time	50 ns
Video output	0.1 to 2.1 V

se specifications will be used to illustrate four areas of ern to engineers today.

k of dynamic range

he transfer characteristic of a log amplifier is a straight when the output, in volts, is plotted against the input, lBm. As shown in Fig. 1, the slope of the reference lifier is a constant and may be expressed as mV of out per dB change in input. Slope, therefore, defines amic range when related to output voltage. Generally, gain of a log amplifier cannot be defined in conventional ns; the slope and the end points of the curve are specified instead. In the log amp defined above, the transfer slope is 25 mV/dB.

The dynamic range of a log amplifier can be checked easily enough by using a pulsed or CW source. However, avoid using a pulse generator that has a poor on/off signal ratio. When using a pulsed CW signal source, the turnoff characteristic of the source shows up as a video pedestal in the output. For example, if the generator is set at 0 dBm, the top of the log amp output pulse is at the 2.1-V level. If generator output was completely turned off, no pedestal would be seen since the pulse bottom at the log amp output would be at (or very near) 0 V.



1. A plot of a log amp transfer function reveals its accuracy; in this case ±1 dB over an 80-dB range.

But difficulties arise if the pulsed CW source doesn't turn off completely—for instance, if the output voltage dropped from 2.1 V to 0.85 V. This would indicate that the input signal had dropped by only 50 dB (2.1-0.85/0.025 = 50). Assuming the video output is DC-coupled, generator leakage appears as a DC pedestal. The AC component of this signal generator seen in the video output appears to remain constant from an output level of 0 dBm down to −30 dBm.

The important fact to remember is that the amplifier is logging over a wide dynamic range; the user sees this range displayed instantaneously. In a linear system, a voltage level 40 dB below the top of the pulse might be obscured in the base line of an oscilloscope display. But using a log amplifier with an 80-dB dynamic range, an output level 40 dB down

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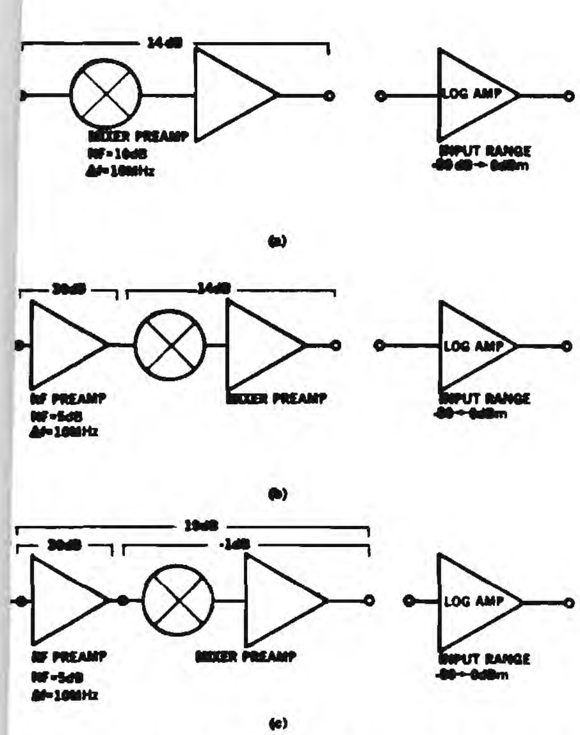


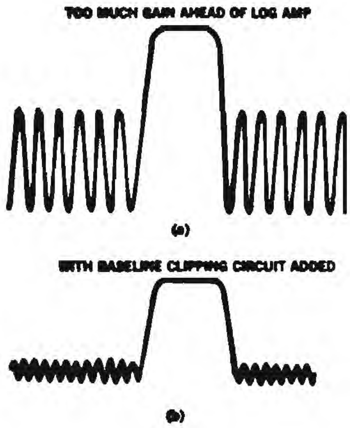
on't provide too much gain ahead of a log amp. ɹced dynamic range can result. In (a), equivalent t noise at the mixer preamp is −94 dBm and −80 dBm e output. Usable dynamic range is 80 dB. In (b), an RF mp with 30 dB gain precedes the mixer. Noise ributed by the preamp moves the dynamic gain range low upwards on the transfer curve. Net dynamic ıe has been reduced by 25 dB. A cure for reduced amic range is shown in (c). The preamp has less gain dB) than in (b) (30 dB). By lowering preamp gain, em noise is reduced: the 80-dB range is restored.

ɜrenced to the top of a 0-dBm pulse) appears halfway n, or at the 50-percent point.

roviding too much gain ahead of the log amplifier also the effect of reducing dynamic range. In most systems, log amplifier is preceded by a mixer-preamplifier, as wn in Fig. 2(a). The equivalent noise at the mixer preamp ıt is −94 dBm and −80 dBm at the output. Note that noise power (−80 dBm) presented into the log amp lies he bottom end of its dynamic range (−80 dBm). The em, therefore, has a usable dynamic range of 80 dB. ı Fig. 2(b), an RF preamplifier with 30-dB gain is added. ıe equivalent noise at the RF preamp input is −99 dBm, noise presented into the log amp is −55 dBm. The input ıe to the log amplifier is now 25 dB above the logging ɜshold of—80 dBm. As a result, net dynamic range has n reduced by 25 dB.

'igure 2(c) illustrates a possible cure for such a system ere an RF preamplifier is involved. The use of a low-noise preamplifier will generally improve the sensitivity of the system by several dB since the noise figure of such a preamplifier will usually be less than the mixer preamplifier noise figure. However, the top end of the dynamic range is reduced by the use of an RF preamplifier and the overall system dynamic range will generally be less, unless a configuration such as that shown in Fig. 2(c) is considered.

The equivalent noise at the input to the RF amp is −99 dBm. To present noise at −80 dBm to the log amp requires an overall gain (RF preamp plus mixer preamp) of 19 dB.



***3. Baseline clipping** is one method used to improve the apparent system signal-to-noise ratio. But a loss of dynamic range is one drawback of this technique.*

Since the RF preamp has 20 dB of gain, the mixer preamp must have −1 dB of gain. Based on a 7-dB mixer conversion loss, a preamp with 6-dB gain is required. Net mixer preamp gain is therefore −1 dB.

In a practical design, opt for approximately 10-dB gain, and adjust mixer preamp output with a resistive pad. Be sure the amplifier/pad combination has greater than 0-dBm output capability to preserve the top end of the dynamic range.

What happened to my SNR?

In a linear system, signal-to-noise ratio (SNR) is usually not affected by changes in gain level. The opposite is true of a system using a log amplifier. Consider the case of systems with and without an RF preamp, as shown in Figs. 2(a) and 2(b), respectively. In both, the signal level at the antenna is assumed to be −60 dBm. In Fig. 2(a), a −80-dBm noise level at the log amp input produces an output of 0.1 V; an input signal of −46 dBm (−60 dBm + 14 dB) lds an output of 0.9 V. System output SNR, therefore, 9:1.

:n Fig. 2(b), both the noise level at the input to the log ıp and the signal level at the log amp have been increased 30 dB. The signal produces a log amp output of 1.7 V; noise floor, however, is at 0.8 V. So the apparent signal-noise ratio is now slightly over 2:1. The point here is to ıintain the effective noise power at the log amp input as ›se to the bottom of the log transfer curve as possible. it is not practical to change the system ahead of the log ıp, consider reducing the log amp sensitivity by either ding a resistive pad at the input, or modifying the basic sign. Adding an input pad will move all signal levels down the log curve. So, the output of the device ahead of the g amp must have a high enough output capability to reach e top end of the log amp input dynamic range (0 dBm) ith the pad in place. For instance, if a 10-dB pad is inserted ıead of the log amp, the driving amplifier needs a top-ıd capability of at least +10 dBm.

Another method used to correct poor SNR is baseline ipping. However, this cures the symptom not the cause, ıd still results in a loss of usable dynamic range. If baseline ipping is used (Fig. 3), excess noise ("grass") can be sliced 'f the bottom. The signal-to-noise appears to be improved.

andwidth variation: Why?

In a typical log amp, the bandwidth often appears to roaden and be, at the same time, sensitive to signal level. Vhy? This is normal logging action.

The key factor is our definition of bandwidth: the 3-dB oint is *not* 0.707 of the output. Remember, using the mplifier example chosen, the output slope is 25 mV/dB n the logging region. The 3-dB bandwidth is therefore epresented by the frequencies where output is down 3 x 25=75 mV.

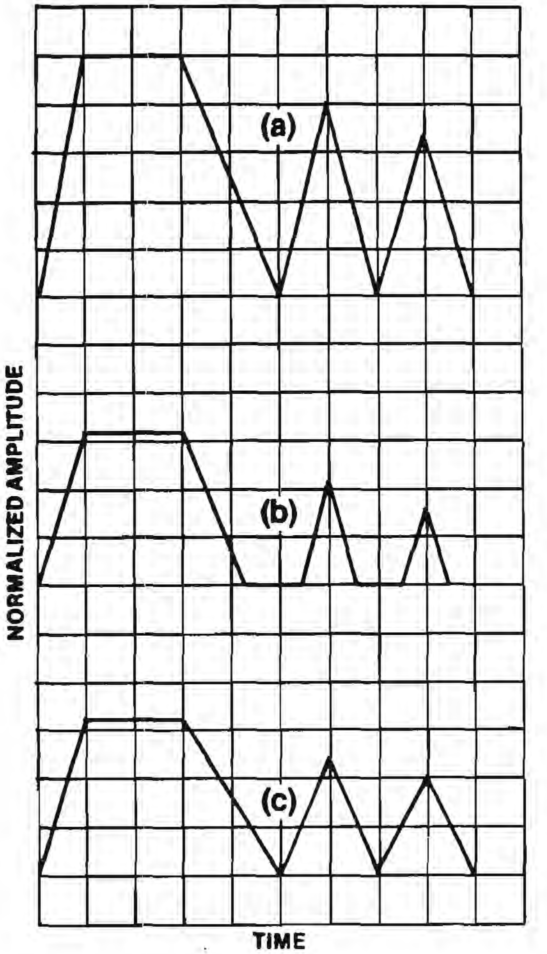
If the log amp incorporates an input filter to establish he desired bandwidth, the stages which follow generally ıave a much wider bandwidth than the input filter. This ırrangement minimizes variations in bandpass and overall ımplifier time delay. The latter is important when time-›f-arrival information is critical. Typically, a log amp will exhibit delay variations of 25 percent of the rise time over its dynamic range.

Watch pulse fall time

In a properly functioning log amplifier, the pulse fall time changes with signal level, and is apparently "stretched;" this shows that the amplifier is logging. In a linear system, fall time is the time interval for the pulse to fall from its 90 percent point to its 10 percent point, a level decrease of approximately 19 dB. Since the input pulse decays exponentially, it falls another 19 dB in the next "fall time." If the peak pulse level is 76 dB above the logging threshold, it takes 76/19, or 4 "fall times" to reach the baseline. Thus, if the input pulse has a fall time (amplitude declining from 90 percent to 10 percent) of 0.2 μs, it will take 0.8 μs to reach the logging threshold.

Pulse fidelity vs. junk

A properly designed log amplifier exhibits good transient response over the full dynamic range. The engineer can verify this with a lab bench evaluation, yet find that in the system the pulse contains spurious components ("junk"),



4. Spurious components (junk) oftentimes *appear on the trailing edge of a pulse. These can lead the designer to diagnose faults either within the system or elsewhere. In (a), the true trailing edge of a pulsed IF signal is displayed. By reducing the IF level, the engineer can tell if the pulse is in the signal (b), or in the log amp/video processor (c).*

Figure 4(a) shows a typical example. Here, the junk reflects the true trailing edge of the pulsed IF signal being fed into the log amplifier. This was not visible before, but is seen now that a wide-dynamic-range signal is being viewed instantaneously.

If the input signal is at a 0-dBm level, the 50-percent point of the log video output is 40 dB below the pulse top, and is probably invisible on a linear display. (Using an oscilloscope with a 4 cm/division display, a signal 35 dB-down is a scant 0.4 mm above the baseline.) But viewing the same pulse via a log amp offers an engineer the opportunity to see the pulse characteristics clearly over the full dynamic range.

To verify that garbage viewed is part of the pulse, and not in the system, reduce the input IF level by 30 dB. If the abnormality stays down the same number of milliwatts it's part of the signal (see Fig. 4(b)). But if it scales down (stays at the same percentage point), as in Fig. 4(c), it's introduced by the log amp and/or video processor.••

How to test, what to measure

ing the following techniques, : users are able to perform e basic tests of a log amplifier. e are essentially two primary surements and two secondary . The primary measurements og transfer function and pulse ity; the secondary meas- nents are bandwidth and noise er output.

Log transfer function

most accurate way to observe transfer function of a log lifier is with a log amp test set as the TSL series of instru- ts developed at RHG. The set sists of a crystal oscillator, h when switched off, provides e exponential signal decaying n to noise. But you can make e measurements using readily lable test equipment.

ipment needed (a):
CW signal source with built-in xternal) calibrated attenuator.
Digital voltmeter.

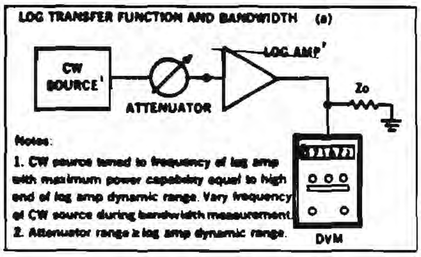
procedure is valid for log s with a direct coupled video out.

Procedure

With the input terminated, and signal input present and with a per output load on the log amp, the DC voltage appearing at output connector using the log DC output adjustment. If a cannot be achieved, note the ding.
Slowly increase the input IF nal level until the DC output ts to rise. Read the input IF l, and the output DC voltage. ord both these readings as the ut signal level is raised in small dB or so) increments. The ac- acy of this plot is primarily de- nined by attenuator accuracy. digital voltmeter should not tribute errors.

Pulse fidelity

uipment needed (b):
Pulsed IF generator (such as Kay Radapulser)



(b) Suitably fast oscilloscope
(c) Attenuator, if not built into generator

Procedure

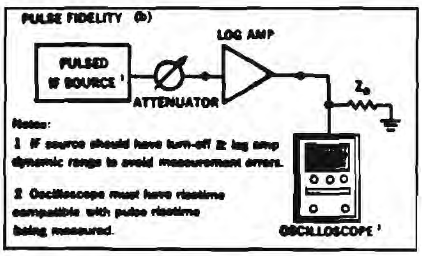
(1) Connect the IF source to the log amp.
(2) Connect the video output to a scope with proper load termination.
(3) View pulse fidelity over its dynamic range.
(4) Confirm the output level amplitude for pulsed vs. CW conditions at a mid-range power level. Some error is to be expected here due to generator power calibration errors.

Bandwidth

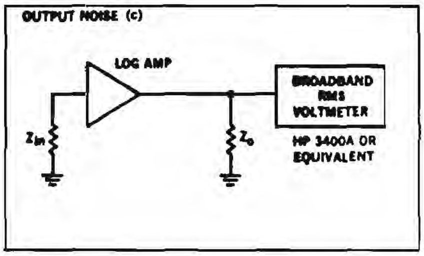
This measurement (or parameter) is generally not important if the pulse fidelity noise measurements are satisfactory.
Equipment needed (a):
(a) Tunable IF signal source
(b) Digital voltmeter

Procedure

(1) Establish an output reference level somewhere in the middle of the dynamic range, with the signal generator set at center frequency.
(2) Take the log slope in mV/dB, and multiply by 3. Using the example log amp, 25 mV x 3= 75 mV.



(3) Hold the signal generator output constant and vary its frequency above and below center frequency to a frequency where the output is reduced by 75 mV. This point represents the 3-dB bandwidth.



Output noise

The noise output of a log amp is directly related to its bandwidth, noise figure, and of course, gain. Measuring noise figure is difficult at best, and generally not too meaningful; it does not provide a good indication of the noise power output.

A more important measurement is the output noise which is readily measured.

Equipment needed (c):
(a) RMS voltmeter with bandwidth compatible with video response of log amp. For the log amp example, a voltmeter with 10-MHz bandwidth is desirable such as a HP3400A or equivalent.

Procedure

(1)Terminate the log amp input and output appropriately. Measure the output noise. This noise measurement is now indicative of the log amp's contribution. To establish that this noise is not limiting the overall system, take the measurement again with the system ahead of the log amp connected. If the reading is not at least 3 dB higher, system parameters should be reviewed. Typical log amps with sensitivity and bandwidths of the type reviewed here will show 100 to 200 mV RMS output noise.••

Terminal-Oriented Computer-Communication Networks

MISCHA SCHWARTZ, FELLOW, IEEE, ROBERT R. BOORSTYN, MEMBER, IEEE, AND RAYMOND L. PICKHOLTZ, MEMBER, IEEE

Invited Paper

bstract—Four examples of currently operating computer-com- ication networks are described in this tutorial paper. They in- e the TYMNET network, the GE Information Services network, NASDAQ over-the-counter stock-quotation system, and the puter Sciences Infonet. These networks all use programmable entrators for combining a multiplicity of terminals. Included in discussion for each network is a description of the overall net- k structure, the handling and transmission of messages, com- ication requirements, routing and reliability consideration where icable, operating data and design specifications where available, unique design features in the area of computer communications.

Introduction

DATA NETWORKS of various kinds are currently in operation, are in the process of being set up, or have been proposed for future development and construc- 1. They include large-scale computer networks (e.g., the vanced Research Projects Agency (ARPA) network and ilar networks under development in Europe and else- ere), multipurpose data networks (e.g., AT&T, Western ion, and the system proposed by Datran), airline reserva- n systems, bank transaction systems, retail chain data- w systems, stock information and securities exchange net- rks, medical data networks, geographically dispersed time- red computer systems operated by various computer vice organizations, public service networks (combining e, police, health, and other vital functions) under develop- nt in various urban areas, educational data networks, etc. e list is seemingly endless and growing larger literally day day.

Although the applications and uses for which they are in- nded cover a broad spectrum of sometimes overlapping ta-flow functions, and although the designs entailed may ver a seemingly bewildering variety of approaches, all these tworks are similar in their symbiotic mix of computers and mmunications. It is for this reason that we find them beled computer-communication networks. It is also no cident that the traditional common-carrier companies, the mputer manufacturers, and computer-communication com- nies are all vitally interested in this burgeoning field.

Although the variety of networks in existence or under velopment is large, and their design philosophies are often mplex—often based as much on questions of history and iginal applications for which they are intended as on up-to- te technical and cost considerations—a detailed overview ay bring out similarities in structure and design (as well as ferences), and inject some order into the seeming chaos. It for this purpose that this tutorial paper has been written. It is geared to the nonspecialist in the field of computer-communication networks, interested in obtaining an overall view of how the interaction of computer and communication facilities is used to manage the data flow in rather complex networks.

We focus here by way of example on terminal-oriented networks, those designed to accommodate input–output devices, such as Teletypewriters, push-button control units, and their associated display devices, where they exist. The network design and design philosophy is then predicated on providing the appropriate services to these terminal-type users. Four existing networks will be described in some detail so that comparisons can be made in the overall system design, in message formatting and processing, in data-handling capability, etc. These particular networks (the NASDAQ over-the-counter stock quotation network, the Computer Sciences Infonet, the Tymshare TYMNET, and the GE Information Services Network) are typical of many of the other networks in existence and were chosen because information concerning their design and operation was available or could be obtained readily. (Acknowledgment is given at the end of this paper to individuals consulted in the gathering of the necessary information.)

Except for TYMNET, the pattern of data flow in these networks is generally inbound from a particular terminal to a large computer (or group of computers) that carry out the data processing and/or data retrieval that may be called for, and then outbound back from the computer to the same terminal. This contrasts with a more general network in which data could be switched or routed from one terminal to one or more others, geographically distant, either going through a computer or sets of computers first, or directly to the other terminals. TYMNET provides an example here. The Western Union Telex and TWX systems, among other networks, the AT&T public switched network, and the proposed Datran system provide other examples of this more general type of message routing. The basic concepts of network design and data handling, derived from a comparative study of these four network examples, are thus appropriate to a large class of networks, including those with more complex routing strategies.

Overall View

Before undertaking a summary of the four networks mentioned, it is appropriate to attempt an overall view of the terminal-oriented computer-communications network. This will serve to put the networks described in focus and to enable some sort of comparison of network designs and operations to be made.

Two distinct tasks may be distinguished in the design of any network: 1) the problem of putting a terminal on line, when it desires service, combining its messages with those of

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ier, geographically contiguous terminals; and 2) the prob- of then directing the resultant message stream to the propriate destination for further processing. We can call se tasks, respectively, message combining, concentration, multiplexing, and message distribution or routing.

In the message-combining phase the individual message aracters, once in the system, may be recoded to a standard- d message character format (generally the United States America Standard Code for Information Interchange SASCII) 8-bit character code) for use throughout the work, if different types of input devices may be used in network. Additional bits or characters may be added for or control, addressing, synchronization, and other neces- y control purposes. The combining function itself may be ried out in a variety of ways: a polling technique may be ed in which terminals associated with the particular con- ntration point are regularly (or irregularly) asked to nsmit any data ready to enter the system. The combiner y have a fixed number of input ports to which the termi- ls are either always connected, or to which they may be nnected, if not already occupied. Messages may be fed ectly into a buffer in the combiner, after address bits are ded, and then the buffered messages taken out, either quentially or following some priority scheme.

Note that the combining procedures [13] vary from rather nple multiplexing schemes to sophisticated concentration hemes requiring a small computer [14] to carry them out. e incoming messages may be directly multiplexed onto tgoing trunks, using either frequency-division modulation DM) or time-division modulation (TDM) trunks, or multi- exed onto the outgoing trunks after buffering and some eliminary processing of the type noted previously. Corre- onding to these two alternatives, two types of networks are rrently in use or under development—the line- or circuit- itched type and the message-switched or store-and-forward pe.[1] (Some planned networks call for a combination of the o.) In the line-switched system multiplexers are used roughout the network to allow entry of messages and their ntinuous transmission throughout the network. Here, as in e analogous public switched-voice telephone network, a rminal desirous of entering the network calls in its destina- on. A complete path is set up, from end to end, and then, ce the complete connection is established, messages may be ultiplexed into the system. In the message-switched case a essage may enter the system at a message concentrator, eeuing up or being stored in a buffer until the outgoing unk is ready to accept it, and then work its way through the twork, from concentration point ("node") to concentration int, queuing up at various points if necessary, until the stination is reached.

The line-switching system, requiring only multiplexers r the combining function, may be considerably less costly, uipment-wise, than the equivalent message-swtiching sys- m. The latter requires as its combiner a small computer inicomputers are often used). These latter devices have en variously labeled *communications processor*, *program- able concentrator*, *message concentrator*, and the like [14], 5]. Because of their computational capability these devices n, however, carry out some processing normally associated th larger computers in a system, and they may do the rout- ing and switching associated with switching computers in the line-switched system. They are of course quite flexible and can be programmed to accept various types of terminals at their inputs; they may carry out some control functions, etc. Because of their buffering capability they can smooth out statistical variations in the incoming data—number of termi- nals vying for service, lengths of messages and frequency of message transmission of a particular terminal, etc.

For example, a terminal that transmits short messages spaced at relatively long time intervals apart, once connected into the system, might find a programmable concentrator type of combiner and message switching throughout the net- work more economical for its purposes. For the terminal then *shares* the network facility with the other terminals con- nected in: it is charged only for the time that messages are actually transmitted, and messages from other terminals fill in the empty time gaps. The same terminal connected to the line-switched network must pay for the *entire* time it is connected, just as in telephone transmission, for it has a channel *dedicated* to its use throughout the connection time. Conversely, a data terminal with relatively long messages, spaced close together, may find the line-switched network more economical for its purposes. But this is not a clear-cut situation—it depends on trunk line costs, type of service available from the common carrier if leased lines are used, etc. (For example, the same terminal transmitting short messages may receive long messages back from the computer. Full duplex lines—those capable of handling two-way traffic simultaneously—are commonly used, and the line capacity would then be dictated by the outbound computer–user message stream. The inbound lines are then very inefficiently used, but current communication line costs do not warrant any change in this procedure.) The systems to be described in the sections following provide message switching in the sense previously described. (TYMNET system personnel prefer to use the words *virtual line switching* to describe the function of their network, however, because of the use of dedicated paths or routes once a connection is set up. This will be dis- cussed in more detail in the next section.)

The message distribution or routing task, once the messages from geographically contiguous terminals are com- bined and formatted for transmittal, consists, of course, of directing the messages to their appropriate destination. Various design questions immediately arise here. In mention- ing message concentration or multiplexing we did not at all indicate the placement or location of the combining point. This is part of the rather broad or global question of overall network design [16]—where shall the network nodal points be placed? (These are the points where terminals are concen- trated or multiplexed, where messages may be dropped, where they may be further mutiplexed with other message streams in a hierarchy of multiplexing procedures, where they may be rerouted, etc.) Involved here are questions of cost, reliability, network response or delay time, trunk or link capacities, etc. These are all interrelated and much of the network design, as will be noted in the examples following, involves a mixture of some analysis, simulation, and engineering "feel" for the problem.

Specifically, what are the tradeoffs, cost-wise, in adding more concentrators to cover widely dispersed terminals and decreasing cable costs correspondingly, or vice versa? What capacity (in bits per second) trunks are needed to cover the anticipated traffic between nodes (these are called the *links* of

[1] The term "packet switching" is sometimes used in place of "message itching."

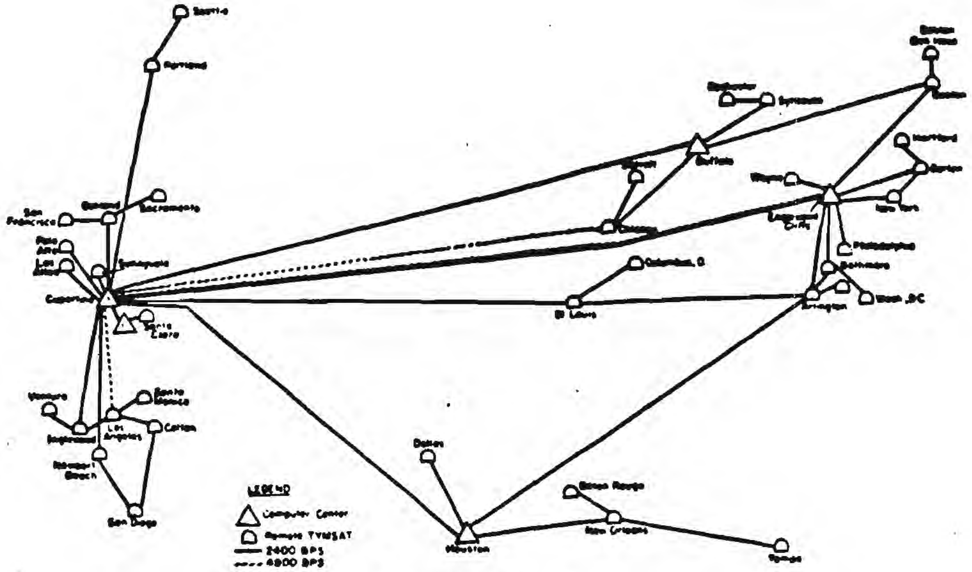

Fig. 1. TYMNET map.

network)? How many terminals can a given combiner dle? Both of these latter two questions are related to the work delay or response time, a typically important con-int in network design. In the case of a message-switched work, increasing trunk capacity decreases the queuing ffer) time of messages as they traverse the network and ce reduces the overall response or delay time. In the case a line-switched network, the chance of a busy signal is iously reduced as capacity is increased. In addition, as vision is made for more terminals to be handled at any centrator, the outgoing trunk capacity must be increased respondingly to handle the additional traffic and keep the ponse time acceptable. The network performance criterion ometimes given as an average or median response time, or e related measure. Alternatively, it may be given in terms tolerable busy-signal probability.

Reliability also plays an extremely important role in net-k design [16]. Systems are often designed to ensure at t *two* alternate paths between any two nodes in the net-k. In some cases this is accomplished by using two graphically separate trunk connections, in others by gning the network topology to ensure an alternate route ween any two nodes if any link in a given route is inter-ted.

Finally, once the network design is established, routing tegies must be established in those networks in which sages may traverse several modes before arriving at a ination. Examples will be given in the systems to be sidered of strategies adopted in practice. It is apparent the routing procedures are related to the reliability straint. For should a link in the network fail, an alternate e must be used. Routing is also an attempt to equalize traffic and response time throughout the network— sages should be sent via routes that carry relatively less fic and that are relatively less error prone than other es. The route set up for a given user–destination pair may globally determined by a centralized computer that moni- the state of the entire network, or, locally, by each node ing estimates of least time to any other node in the net-k and corresponding paths to follow. In the message-ched networks the nodal processors are often used to carry out the processing needed to determine the message routing or to direct messages following the directions from the centralized source. The routing strategy in the line-switched network case is generally determined beforehand and used to search out a complete route or circuit before allowing messages to enter the system. In the message-switched network case, the routing can be adaptive and updated periodically, or on demand, as traffic conditions change.

TYMNET

Overall Network

A recent article has stressed the fact that time-sharing companies have in the past two years moved dramatically beyond their initial phase of providing service for the "one-time problem solver" [1]. The networks they have set up have begun to emerge as national computer-communications net-works, in the fullest sense of the words: they are used to provide computer power and access to data bases for various businesses, often replacing or augmenting expensive in-house computer operations, as well as providing a data-com-munications facility for connecting user computers and remote terminals.

Tymshare, Inc.'s TYMNET computer-communication network exemplifies this change in function and approach. The network, as shown in the accompanying map (see Fig. 1), is a sophisticated data-communications network employing 80 communications processors deployed all over the country to access 26 large host computers located at computer centers in Cupertino, Calif.; Englewood Cliffs, N. J.; Houston, Tex.; and Buffalo, N. Y. (The European network CETNET has been operational for two years with one XDS 940 com-puter located in Paris. The two networks were scheduled to be connected in September, 1972.) The communications processors, called TYSMATS, use modified Varian 620 com-puters. Twenty-three of them serve as so-called base com-puters (base TYMSATS), each associated directly with its own central processing unit (CPU); the other 57 form remote nodes (remote TYMSATS), through which individual termi-nals gain entry to the system. The 26 large computers include 23 XDS 940's and 3 PDP 10's.

The network topology, as shown in the map (see Fig. 1), been laid out following any specific design strategy. essentially just "grown" in response to customer's r to the business expected in various areas. Unlike the other time-shared networks (see, e.g., the section GE network following), the network configuration is y that of a multiple ring rather than a star, although, ing on the traffic expected at any node, some of the ire connected daisy-chained or in a star fashion, in n to the ring configuration [2].

it of the 48 links connecting the various nodes are ıp of leased 2400-bit/s full duplex trunks. Any one concentrator may have as many as 200–300 terminals ted with it. But no more than 31 terminals at any one in have full duplex access to the concentrator. A termi- ning the network gets a local number to call, connecting closest node. The network may be extended with the n of a new concentrator if business in any one nodal approaches or exceeds 31 simultaneous users during the our.

ce the network is of the store-and-forward type with iters used to carry out processing and routing at each it would normally be called a message-switched system sense indicated in the Introduction to this paper. NET personnel and publications [3] prefer to consider twork a *line*-switched network in a *virtual* sense, how- a user calling into a particular node is assigned a route or al channel" (circuit) through the network to the ap- ate CPU. The user keeps that virtual channel through- ansmission. The route is assigned by a supervisory pro- maintained at one of the CPU's. The routing algorithm, cting the set of links between user remote TYMSAT and ppropriate CPU that comprises the virtual channel, es an unused virtual channel and avoids links that are ly loaded or that have a high error rate. A heavily d link is one that is carrying 57 users over that link in ame direction. A high error rate means at least 10 de- d errors in transmission per minute.

ecause of the ring configuration, traffic over any one link, given direction, may be either outbound (computer to or inbound (user to computer). There is no distinction as to direction, unlike the star configuration. Tymshare onnel indicate that the "virtual-channel" or line-switched oach used provides more efficient message transmission: overhead (nondata characters transmitted) is reduced message addressing is much smaller than in the usual age-switched case. (As will be seen later in discussing message format, a one-character virtual-channel number ed for addressing.) Message transmission in the computer- ser direction (the bulk of the traffic carried, as in most -shared systems) can approach 80-percent efficiency, er than the 60-percent figure that might be associated message switching.

sage Transmission

Although TYMNET is often used for computer-to-com- er communication and for driving high-speed peripherals, as primarily designed for the 10–30 character/s terminal. system allows any 10–30-character/s terminal device to ss the network. An identifying character is first typed in. oftware program at the incoming TYMSAT uses the char- er to identify the type of terminal, code used, and speed of racter transmission [4]. All characters following are then verted to American Standard Code for Information Inter-

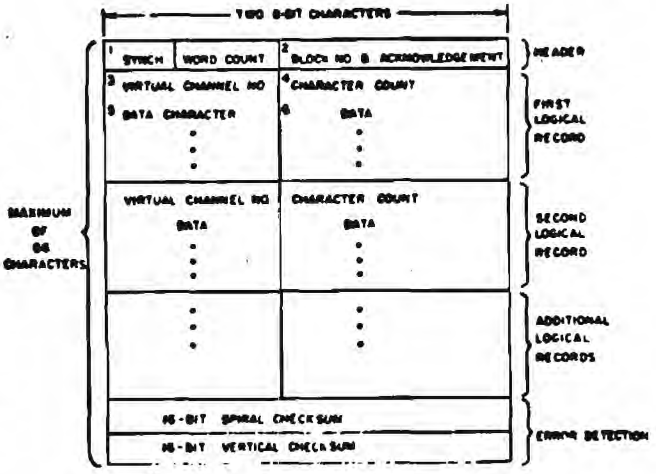

Fig. 2. TYMNET message format.

change (ASCII) (8-bit) code [5] for internal network transmission.

A user calling the TYMSAT with which he is associated is connected in through one of the 31 ports of the TYMSAT. The identifying character he types in, in addition to allowing code conversion at the TYMSAT, sets up a special duplex path to the network supervisor. The supervisor asks for the user name and password, and then uses these to determine at which CPU the user file is located. (Alternatively the user may ask for a particular one of several computers in which he has files.) The supervisor then proceeds to determine and set up the virtual channel mentioned. (This takes of the order of milliseconds.) It sets up the channel by sending control information to each TYMSAT along this route, causing the appropriate entries to be made in each TYMSAT's switching tables. These tables essentially associate a particular channel number with one of the outgoing links from the TYMSAT in question.

Any given TYMSAT handles traffic from its 31 ports as well as traffic coming through from the adjacent nodes to which it is connected. Messages from all these sources are stored (in ASCII code) in character buffers as they arrive. The character buffers as a group occupy 1200 words of core (2400 characters) in the concentrator. This space is dynamically allocated as needed. Each character—whether locally inputted from one of the 31 ports or passing through—has a virtual channel number associated with it.

Message transmission to adjacent nodes is accomplished by assembling a block of characters, from those stored in the buffers, for each outgoing link. A block is assembled by searching through the character buffers, on a first-come-first-served basis, for those characters with virtual channel numbers associated with that particular link (i.e., those virtual channels associated with that link in the TYMSAT switching table). The search continues in round robin fashion (returning to the first buffer queried for additional characters that might have been entered in the interim) until a maximum of 66 characters, including control and error detection characters to be discussed below, have been assembled. If fewer than 66 characters are assembled, whatever is available is transmitted. If there are no data to be sent, control characters only are transmitted.

The format of the block as finally assembled is shown in Fig. 2. A 16-bit header is first transmitted. This consists, in order as shown, of a 4-bit synchronization pattern, a 4-bit a concomitant increase in speed. Since each node is tially an independent module, new hardware and soft- can be phased in one unit at a time. (The software used esent at each node is of the order of 4000 instructions. pecial hardware used is also very primitive. It is there- elatively easy to convert to another minicomputer if sary.)

me words on the supervisory concept are in order [3]. ted earlier, a supervisor handles channel assignment and ng. This is actually a program run under time sharing of the XDS 940's. In addition to establishing an initial or virtual channel, the supervisor will reroute all cir- affected by node or link failures, if an alternate route can und. (Node failures have in practice been infrequent, ging 1.4 failures/year/TYMSAT.)

o guard against supervisor failure, three other host com- s have supervisory programs running as well, arranged predetermined pecking order. (The CPU in Paris will in a supervisor as well when the two networks are d in September.) These dormant supervisors receive ges from the active supervisor about once a minute, con- ng its activity. If a confirmation is not received, the next visor in order takes over. The dormant supervisors no prior knowledge of the state of the network, so that ew supervisor must learn the network. It does this by ng the network systematically node by node and link nk until an up-to-date representation of the network ding, for example, all virtual channels and the contents nodal switching tables) is constructed in its memory.

his centralized supervisory control provides the following res [3].

The individual nodes have no global knowledge of the ork. They may thus be handled independently. The soft- in one does not affect the software in another, simplify- ny debugging necessary.

A newly activated supervisor has no prior knowledge e network. It simply accepts the network configuration exists. Changes in the network are thus easily made.

The fact that the supervisory programs are run under sharing provides debugging advantages.

All global information about the network is available e place; this facilitates diagnostics, record keeping, and gging.

GE Information Services

ll Network

he GE Information Services Network is also an example computer-communication network that has in the past years evolved from an initial phase of providing time- d computer service for the problem solver to the current of providing facilities as an information network. For ple, it now offers a service called *Interprocessing*, in h files may be transferred from a customer's own com- r to the GE System computers for accessing by the cus- r's own terminals that may be geographically dispersed ghout North America and Europe. Pontiac Division of ral Motors, as an example, uses this service to provide -date information to several thousand car dealers [1]. he network, as shown in the accompanying map (see 3), covers the United States, portions of Canada and ico, plus Europe. The configuration follows a hierarchical

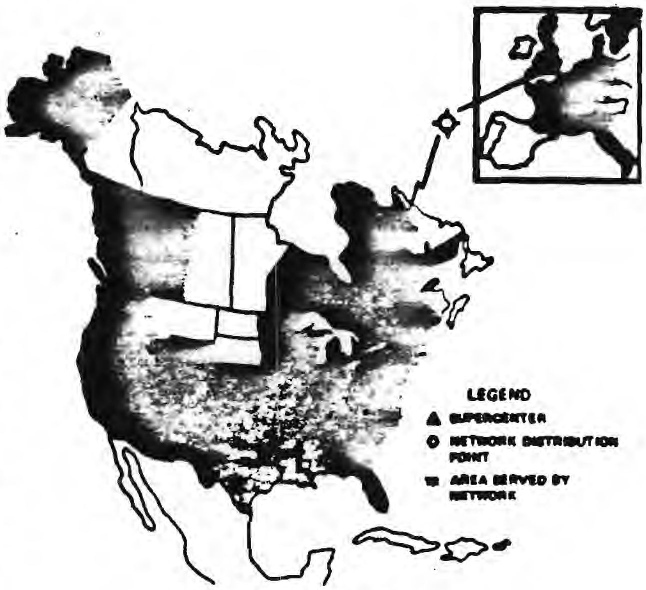

Fig. 3. GE network map.

or a tree-like structure: individual terminals are connected into remote concentrators located in 13 U. S. and 3 European cities. (These are indicated as distribution points in the map.) The remote concentrators are in turn connected to central concentrators located at the main computer center in Cleveland, Ohio. The central concentrators then access the computer systems that are at the heart of the network.

The approximately 50 remote concentrators consist of modified Honeywell 416's with 16K word (16-bit) memory. The concentrators have 48 ports connected to the public switched telephone network, via local loops, foreign exchange lines, or multiplexed lines. A customer wanting to access the network dials a number that connects him to an available port. At the periphery of the network there are some FDM multiplexers used that combine up to three ports before coming in, on a local loop, to the remote concentrator. Local telephone numbers are available in more than 250 cities.

Most of the communications cost of the network is in the local loops, and the remote concentrators are generally placed to reduce these costs. There may be several remote concentrators located in heavy load regions.

The remote concentrators are connected via full duplex 4800- or 9600-bit/s lines to the central concentrators in Cleveland. Two alternate paths or circuits are available to maintain reliability. The central concentrators consist of GEPAC 4020 computers. Each central concentrator may have a maximum of eight remote concentrators connected to it. A central concentrator in London, England, fed by three remote concentrators for European traffic, is also connected to the central concentrators in Cleveland. Satellite and underwater cable are used to provide the alternate-path reliability in this case.

Each central concentrator in turn is connected to a number of large computer systems. The number connected ranges from one to six and depends on the type of computer system. (Fewer Mark II systems will be served by the concentrator than Mark I systems. These terms are briefly explained in the following paragraphs.) Each central concentrator is also con-

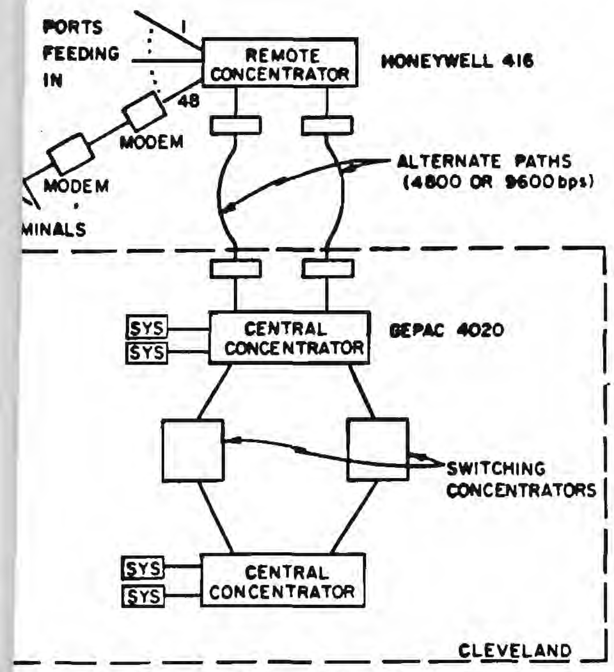

Fig. 4. GE network hierarchy.

d to two switching concentrators located within the building that connect users coming in on a particular al concentrator to the one associated with the computer m holding their files. The process is explained schemati- in Fig. 4.

our types of computational service are available from ystem, each corresponding to a particular one of the uter systems previously noted.

) Mark I time-shared services. This is essentially a em-solving service. It handles the Basic language, some , and a simple version of Fortran. This service is an owth of the original Dartmouth-designed system. It is ntly handled by Honeywell G-265 computers.

) Mark II time-shared service. This is provided by a ber of Honeywell G-635 computers. It is the largest and used system in the network. The system is the out- th of a joint Dartmouth–GE project and was com- ially introduced in 1968.

) Mark Delta service. Provided by Honeywell G-605's, is the most demanding system in terms of the customer's ty to program.

) Resource service. This service provides remote batch essing plus some time-shared service and is handled by oneywell 6070 system.

n addition, a Mark III system is due to go on the air by hird quarter of 1972. In this system multiple Mark II's be coupled to a Honeywell 6080 (a much larger machine) atch processing.

lthough the fundamental design of the current network out of the original Mark II time-sharing system de- ped at Dartmouth, the network, as it exists at present, is different. As in the case of TYMNET discussed earlier, network has essentially evolved in response to market and and customer needs, with incremental changes made equired. It is a store-and-forward *message-switched* net- , as will become apparent in the following section. The use of remote concentrators provides flexibility in accepting various types of user terminals and in adjusting to market demands.

Message Transmission

Any terminal transmitting up to 30 characters/s (300 bits/s) may be used to access this system. The remote concentrator will convert non-ASCII code inputs to ASCII, used throughout the system. Identification of the machine, speed, and code used is accomplished by typing in the letter H. The sign-on procedure consists of typing in this identifying character, followed by the user number. This number is forwarded by the remote concentrator to the central concentrator to which it is connected. Each central concentrator has a user table showing the central concentrator associated with the computer system responsible for each user, thus indicating the appropriate computer or central concentrator to which a particular user message should be forwarded. Following the user number a password is typed in. This is checked against the password stored in the user system to see if it is valid. The user is then ready for transmission.

User inputs are of two types generally. These consist of system-command and file-building-mode messages. The file-building mode begins with a line number. The characters following, up to 150 in number, and comprising a line, are stored in the remote concentrator message buffer. (Recent characters or the entire line may be deleted if the user desires.) The line is concluded by depressing the carriage-return key, causing one or more messages of up to 36 characters to be transmitted, with appropriate overhead characters added to the appropriate computer system. (Note that this differs from the TYMNET format, in which messages from various users may be combined to form one block.) System-command messages with no line number at the beginning are handled as priority messages and sent right out as received. (There is no echoing in this system. Characters are printed by the *terminal* as soon as the key is depressed.)

The message buffer at the remote concentrator is dynamically managed, with space allocated to terminals that need it, on demand. Buffer allocation to any one terminal is based on terminal speed and mode. Messages flowing in either direction (user–computer or computer–user) use the same set of buffers and are provided the same buffer allocation. GE personnel indicate that the buffer sizes are quite sufficient with very little message queuing taking place at this point.

The message format, in block form, uses a modified version of the ASCII format [5]. It consists of 9 characters of overhead and from zero to 36 characters of text. The same format is used in both directions of data transmission. As shown in Fig. 5, the first 7 characters constituting the header consist, in order, of 1) an ASCII start-of-header (SOH) character, 2) the port number of the remote concentrator, 3) the number of the remote concentrator (R/C), 4) the length of text following, 5) type of message character, 6) a control character for setting up a function, and 7) the ASCII start-of-text (STX) character. The text then follows, and the block is concluded with an ASCII end-of-text (ETX) character and an error-detection character. (This final character is the EXCLUSIVE-ORed value of everything but itself.)

Messages are sent, a block at a time, from the remote concentrator to the central concentrator to which it is connected. The path used (of the two available) is the one which is free or the one not used for the last transmission. Each

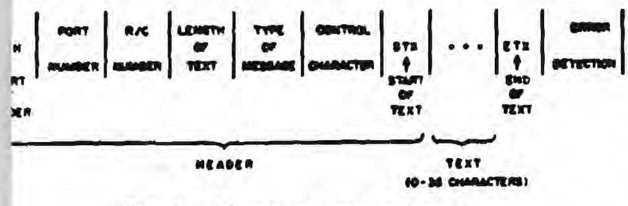

Fig. 5. GE network message format.

:k is acknowledged as received by the transmission over return path of a six-character acknowledgment block. s consists of six of the overhead characters in the standard sage block (see Fig. 5)—the first three characters and the character of the header, plus the last two characters in the :k. If an acknowledgment is not received, the remote con-trator retransmits the message. This automatically pro-:s alternate path selection in the event of a noisy path or uit. Since the remote concentrator selects the path of the available that has been most recently vacant, a noisy uit with a correspondingly increased number of retrans-sions is vacant less often and is hence not used.

A second acknowledgment step is similarly carried out if message must further be switched through the switching :entrators to a second central concentrator interfacing 1 the user's computer system. The switching concentrator ains transparent to this additional acknowledgment step. h remote and central concentrator counts the number of ansmissions over each circuit, and every 30 min the central :entrator prints out on its own console a report on the dition of each circuit.

The process of transmitting a user message to a second :ral concentrator if necessary is first begun with the trans-sion of the user number, as indicated earlier. The central :entrator to which the user message is first transmitted responding to the remote concentrator to which the user nnected) associates the user port and remote concentrator nber with the first character of the user number. This char-:r in the user table, available at each central concentrator, :rmines the central concentrator to which the user message uld be switched. Once log-on is complete and the remote :entrator port-processor association has been established, her messages originating from the same port on the same ote concentrator are accorded the same routing. The sage format in going through the switches is essentially same as that of the transmission format between remote central concentrators, with the addition of two delete racters added after the SOH character plus one character cating the central concentrator for which it is destined. switching concentrator ports are numbered to represent destination central concentrators.

ffic-Handling Capability

The maximum port capacity of the network as deployed une 1972 was of the order of 2000 simultaneous users. This f course the current maximum capacity. The message and ting disciplines used make it possible to expand the net-k indefinitely and to serve computers of many kinds which be located at any major node.

To make sure the network can accommodate the traffic, re is a daily review of the network, in which the following r items are assessed: 1) the assignment of user numbers d hence number of users) to each computer system, 2) the gnment of remote concentrators to central concentrators, 3) the assignment of ports to the remote concentrators, and 4) the deployment of ports.

Based on this assessment, the network topology may actually be changed daily. Thus a computer algorithm reassigns user numbers and remote concentrators daily in an attempt to balance the peak load of the machines. User file catalogs may thus be moved from machine to machine. The reassignments are also facilitated since all programs in the remote concentrators are loaded from the center. The last two items above are changed once a month, or more often if necessary.

The performance criterion used for the network provides a 95-percent probability of port availability on a Poisson basis at the local peak load, generally 2–3 P.M. local time. On this basis roughly 5–6 users can be accommodated per remote concentrator port, for a total of 10 000 individual users for the entire system. There are currently about 3000 firms with varying numbers of individual users validated for use of the network.

GE personnel indicate that response time throughout the network is negligible and is hence not used as a criterion of performance. The only significant queuing occurs within the computer systems themselves. Several queues may exist there, depending on the user's needs. (For example, there may be a queue of programs waiting to be processed.)

Some additional traffic statistics may be of interest. As in most such systems, the outbound traffic (computer–user) dominates. It runs typically 3–5 times the input speed. The average length of messages, outbound, runs 30 characters per line. Although most terminals currently used are 10-character/s units, a growing number are 30-character/s units. Terminal duty factors based primarily on outbound statistics run 70 percent—i.e., 7 character/s on 10-character/s terminals and 21 character/s on 30-character/s terminals.

The NASDAQ System [7], [8], [9]

How the System Is Used

The National Association of Securities Dealers Automated Quotations (NASDAQ) System is a computerized communications system, designed by Bunker–Ramo Corp., which makes available to its users a means of rapidly obtaining quotations on the bid and asked prices of over-the-counter securities. In addition, changes in these quotations, by specially designated users, are rapidly entered into the system.

Each security[2] in the over-the-counter market, which is regulated by the National Association of Securities Dealers, has assigned at least two but not more than 64 traders, specially approved as market makers. These market makers are responsible for individually establishing their own bid (buy) and ask (sell) prices for their security. They are committed to trade at least 100 shares of the security at their price. Previously, a trader receiving a request about a certain security would have to contact, by telephone, a number of the market makers in that security to determine their current prices and, after deciding the "best deal," recontact that market maker and complete the transaction. Often the trader would shorten this lengthy procedure by calling only several of the market makers. Frequently the prices would change before the trader could return to the market maker. Thus it was difficult and time consuming to determine all current prices in a security. Even representative bid and ask prices (median prices of all market makers in a security) were some-

[2] As of this writing there are 3000 securities in the NASDAQ system.

several days old. As a consequence, there were often differences between the prices of different market rs. The NASDAQ system, which began operation on iary 8, 1971, was set up to automate this process.

ow a broker can type in the code name for a security on cial terminal and receive in seconds on a cathode-ray (CRT) display the current representative bid and ask . Terminals which are restricted to only this response are Level I terminals and are not essentially part of the ırk. This, and other information, is also supplied periodi- to the news media. Level II and III terminals receive, dition to the representative bid and ask prices, the ıt bid and ask prices of each market maker in that ty. If a bid price is requested, the market makers are in order of descending bid price. If an ask price is sted, they are listed in order of ascending ask prices.

ır example, suppose a customer wants information on a :ular security. He contacts his broker and immediately es the current representative bid and ask price. If the mer wants to buy the stock, the broker contacts his r, who, using a Level II or III terminal, types in the ıame of the security and an "ask" symbol to denote that ınts the market makers listed in order of ascending ask i.e., the price at which the market maker will sell. narket makers' prices are displayed in frames of up to ıarket makers each. If there are more than five market rs in that security, the characters MOR are printed in the right half corner of the CRT, and the trader, by pressing R key, can receive the prices of the next five market rs. This continues until all market makers are listed. : trader wants to buy the stock from one of the market rs, he calls him on a telephone and arranges the transac-

he Level III terminal, used by the market maker, has ıe capabilities of a Level II terminal. In addition, the et maker can change the bid and ask prices in his ities. These changes are processed by the system in ds.

ıll Network (Fig. 6)

he terminals (Levels II or III) are connected directly to the-counter control units (OCU's). There is one OCU in brokerage office. Although the system is designed so that ı 24 terminals may be connected to each OCU, most s have only a few terminals. The national average of inals per OCU is 1.45 (1.75 in the Northeast, only 1.2 ıhere). The terminals are relatively simple, consisting ly of a specially designed keyboard and a CRT display. : of the work is done in the OCU—buffering, message atting, addressing, etc.

'he OCU's are connected by leased full duplex 1600-bit/s idrop lines to a concentrator. Each of these lines, called ınal circuits, can accommodate up to 32 OCU's. Each entrator can handle up to 48 regional lines. These design ations, and the maximum number of terminals per OCU, lue to the addressing structure, the amount of storage, If the entire capability were used, inordinate delays would t. Thus, to achieve adequate performance, the actual bers are far below these maxima (see Table I).

'he concentrators are located at four sites—New York, '.; Chicago, Ill.; San Francisco, Calif; and Atlanta, Ga. ıe sites were chosen on the basis of expected customer ity and were located at existing Bunker-Ramo locations ıve on the cost of installation. Originally a concentrator at as, Tex., was also planned, but after a network study it

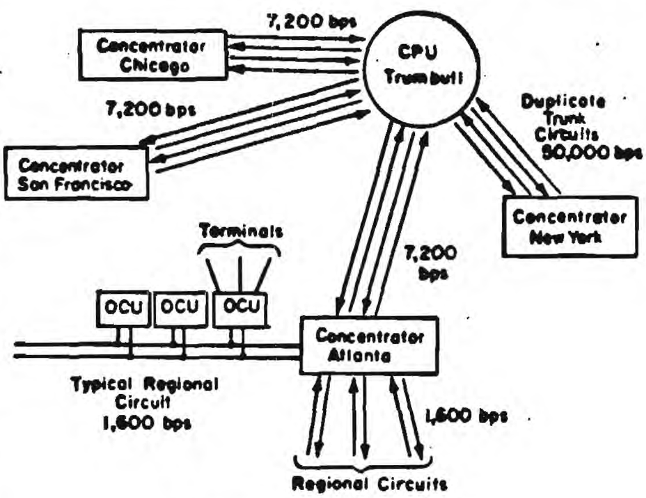

Fig. 6. The NASDAQ network.

TABLE I
NASDAQ SYSTEM CONFIGURATION

Concentrator Location	No. of Regional Circuits	No. of OCU's	No. of Terminals
New York	75	575	[illegible]
Chicago	[illegible]	195	[illegible]
San Francisco	37	170	[illegible]
Atlanta	9	[illegible]	141
	[illegible]	1092	[illegible]

was found that considerable savings resulted from merging this with the Atlanta facility. The concentrator sites in Chicago, San Francisco, and Atlanta consist of a pair of concentrators, each using a Honeywell DDP-516 computer, and other equipment. Both concentrators are always on line and share the traffic. For reliability the system is designed so that if any unit fails, the entire traffic can be handled by the remaining unit. The switchover can be accomplished in several minutes. The New York site contains four such concentrators and has the same redundancy capability. The concentrators poll the OCU's on each regional circuit, store the messages, control traffic to the CPU, and perform multiplexing and other communications tasks.

Each concentrator site is connected to the CPU by a pair of leased full duplex high-speed lines called trunk circuits. Again for redundancy either one of a pair of lines can handle the entire traffic if necessary. Furthermore, each of a pair of lines is diversely routed—connected over separate geographic paths. The trunks connecting New York to the CPU each have a capacity of 50 000 bits/s; the other trunks each have a capacity of 7200 bits/s. The CPU is located in Trumbull, Conn., and contains two UNIVAC 1108 multiprocessing computers, again operating redundantly so if necessary either one can handle the combined traffic. The CPU receives requests, searches its files, responds, updates quotations, and performs other operations of the system. The network is shown in Fig. 6.

Terminals and OCU's (Query Message)

The terminals consist mainly of a specially designed keyboard and a CRT display. A typical query (quote request) message (Level II or III) would be a bid or ask character and the four- or five-character code for a security. (A quote-change message by a market maker would require a slightly longer message. The ratio of quote requests to quote changes proximately 20:1.) Since the connection between the nals and the OCU's is asynchronous, the five characters ach 10 bits long—8 for the ASCII code, including 1 for y, and 2 for start and stop. The OCU's have provisions p to 24 buffers, one for each terminal, arranged in six lines of four buffers each. Thus each terminal has a fic fixed address in the OCU. Each delay line can store oximately 10 000 bits. (Since the reply (return) message y much longer than the query message, and they always in pairs, the network is designed on the basis of the messages. The CRT has a maximum of six lines with 37 cters each and thus requires 2220 bits.) The OCU lly receives these characters from the keyboard and s them in the appropriate buffer. This operation can be dered instantaneous. Once a query message is finished, ated by an appropriate key on the terminal, the message e OCU is ready to be transmitted to the appropriate entrator.

he OCU appends to each query message of five characters SOH character, two characters permanently identifying brokerage office,[3] two characters identifying the OCU ess and the terminal address, one more for control, the y message, one "end-of-transmission" (EOT) character, a horizontal parity character—13 characters in all.

centrators (Query Message)

The OCU's are connected to their concentrators by full lex asynchronous 1600-bit/s multidrop lines arrayed in ral regional circuits. The concentrators have a single er for each regional circuit to be used for the query sage only. The concentrators poll the OCU's on a regional cyclically. The poll messages are two characters long— character to initiate the polling request and a second l for addressing each OCU in turn. If a message is present, message is transmitted to the concentrator; if not, then a character reply is sent to the concentrator. If more than message is waiting at an OCU, only one of these is trans- ted on a single poll. Once a query message is received by concentrator, the polling stops on that regional circuit l that message is transmitted to the CPU. Furthermore, revent any OCU from dominating the traffic, an OCU will be repolled until a response to an earlier query or an error sage has been received. Additional features of the polling multiplexing will be discussed when the reply message is idered. The concentrator inserts two characters into the sage for concentrator and line address. Since the high- d lines connecting the concentrators to the CPU are chronous, each character is only 8 bits long—the start and bits are no longer needed. But three synchronication racters precede the message. Thus the message is a total of haracters.

U

The CPU is connected to each concentrator by a pair of duplex synchronous high-speed 7200- (50 000- in New k) bit/s trunk lines. The CPU has a pair of separate t buffers (three input buffers for the lines from New York) each trunk line. These buffers, each capable of storing 225 racters, are filled cyclically. Messages are routed over each of lines so as to equalize traffic. The CPU consists of two IVAC 1108 processors operating duplexed so that, again for reliability, if any one unit fails, the other can handle the entire load. Similarly, the drums for storing data are duplicated. In addition to its other functions—reporting of prices and indices to the media, supervision of trading, system control, etc.—the CPU receives quote requests, searches its memory for the appropriate security, formats the message comprising the prices for the particular frame of five market makers in appropriate order, and transmits the reply message. If a quote change message is received from a market maker, the files must be updated in that security, including a recomputation of the median bid and asked prices.

The first frame (first five market makers) in any security is more frequently requested than subsequent frames. Thus the first frame is always kept ready for transmission; subsequent frames must be formatted when requested. Furthermore, data for frequently requested securities are stored on readily accessible drums. Data for less active securities require additional time for retrieval. Typical times required for the CPU to respond to the various request messages are 4 ms to process the first frame of a quote request and 8 ms to process a quote request for subsequent frames or a quote change. In addition the average time required to retrieve the data from the files is 4 ms for a quote request and 8 ms for a quote change for active securities, and four or five times this for inactive securities. Thus the total time required by the CPU is, on the average, 8–50 ms.

The reply message is similar in form to the query message, except that the two permanent identification characters for the brokerage firm are not transmitted. The reply message is typically about 115 characters long. The CPU has a pool of 70 buffers, each 225 characters long, to store reply messages. If more than five messages are waiting to be transmitted to any one concentrator on any one trunk, then a message is sent to that concentrator to stop polling for a specified period of time. Typically, during a busy period, 20–30 of the buffers are occupied.

Reply Message

Each concentrator has a pool of 31 reply buffers. (The concentrators will transmit a query message to the CPU only if there is a reply buffer available.) The reply message is then transmitted to the appropriate OCU. An excessive delay would result if polling were to be suspended during the time a reply message is being transmitted from the concentrator to the OCU along the multidrop regional line. To alleviate this, a system of nested polling is used. Two-character polling messages are inserted into the reply message. A result of this entire procedure is that messages are made to wait at the OCU rather than the concentrator.

System Design and Performance

The network design (assignment of OCU's to regional circuits and regional circuits to concentrators) was based upon location of existing Bunker–Ramo facilities (for location of concentrators and CPU), estimates of numbers and locations of customers and frequency of use, and line tariffs for the trunk lines and the multidrop regional lines, taking into account differences between interstate and intrastate rates. Response times called for in the design were a response to a quote request or a quote change within 5 s 50 percent of the time and within 7 s 90 percent of the time. The quote files were to be updated within 5 s at least 95 percent of the time. The system design encompassed the indicated response time assuming a busy-time load of 28 calls/s system-wide.

The following peak statistics have been obtained: 1 262 000 calls on a very busy day, 240 000 calls during a busy hour, and

[3] The assignments of OCU's to regional circuits are infrequently ged to equalize traffic flow. These two characters provide permanent tification of the brokerage office for bookkeeping purposes. The next characters identify the current physical address of the terminal and OCU for message routing.

calls/s during a peak minute—67 from New York, 14 Chicago, 12 from San Francisco, and 7 from Atlanta. The average 1½ calls/min are to be expected per terminal. e this number has been observed during peak periods, even an extreme of 12 calls/min has been observed on a very active terminal. A design rule of thumb that has developed is that a limitation of 20 terminals per regional it will guarantee meeting of response time specifications. during observed peak activity the system is still performing satisfactorily. During such peak activity, however, line redundancy may be lost in certain areas for a certain period if one of a pair fails, but in this event there is a up capability which is used as a second-level backup. In the system seems to be well designed and can even handle c well in excess of what it was designed for.

INFONET

duction

NFONET is a remote computing system conceived and ned by Computer Sciences Corporation in response to requirement for a versatile remote computing environ- which would fulfill the needs of a wide spectrum of oriented requirements. The INFONET system archi- re and communication network are based upon the objec- of providing service to both conversational (10–30 char- s/s) and remote job entry (2000–8000 bits/s) terminals single integrated system and the ability of the network to ve to the next generation of hardware, software, and com- ications.

NFONET has been in full commercial operation in the ed States since January, 1970, and also has networks lled in Canada, Australia, and South Africa. Since the l operation, the network has expanded geographically, a second-generation oprating system and enhanced com- ication network have been installed. INFONET was ntly selected by the General Services Administration to unified supplier of nationwide teleprocessing services for ral agencies.

The operating system for INFONET is known as the puter Sciences Teleprocessing System. This system was ifically designed to avoid partitioning of resources to ort multiple operating modes, but to allow all hardware bilities, operating-system features, language processors, ication programs, and data files to be available for both active and batch processing without special user action. support the single integrated-system concept, the com- ication network for both low-speed conversational access high-speed batch was designed and implemented as a le common network.

Two principal programming subsystems are used—the SIC subsystem and the General Programming Subsystem S). Both systems have access to the full computing re- ce and the same files. BASIC is an enhanced version of the tmouth College BASIC. GPS includes several language essors: Fortran IV, Fortran V, Cobol, Data Management guage, Program Checkout Facility, and an Assembler.

NFONET currently uses six UNIVAC 1108 computers in network. The 1108 has a main storage capacity of 10^6 acters, which is augmented by a magnetic drum subsys- . Immediate-access storage is provided by a Multiple Drive subsystem. Dual access and multiple drives provide roved reliability. Additional storage is provided by eight netic tape drives per 1108 with support for both seven- nine-track recording formats.

Communications Network

The computer centers are in Washington, D. C., Chicago, and Los Angeles. Each location contains from one to three 1108's and associated peripherals. Each functions as a regional center serving several major metropolitan cities via communications concentrators and multiplexers. In addition, the Los Angeles center serves as the national center, providing access on a nationwide basis to customers with requirements for access to common data bases and files from geographically dispersed locations throughout the country. By designing a nationwide system with only three centers and multiple computers per center, INFONET is more dependent upon a reliable communictions network than it would be had it elected to place a single main frame in each of numerous centers. Principal motivations for the small number of centers were the higher reliabilities and longer operating hours achievable with such a configuration, greater flexibility, and user access to common files from diverse locations. Efficient utilization of existing common-carrier facilities also renders this a more economical choice. Recall that both the TYMNET and GE Information Service Networks used a small number of centers as well (see Figs. 1 and 3).

A map of the INFONET communication network is shown in Fig. 7. Only the major cities and the backbone network are shown. The number of circuits connecting each remote branch to a computer center is not indicated; a minimum of two diversely routed circuits are provided. INFONET utilizes one network with common hardware for all comunications—both low-speed asynchronous requirements and high-speed remote batch terminal needs. In order to provide highly versatile communications, a special concentrator was necessary. This led to the design and development of the Remote Communications Concentrator (RCC). The RCC serves as the communications interface for the network and functions as a combination of statistical multiplexer, incremental front end, and error-control device.

A functional diagram showing the essential elements of the INFONET network and their relation to the RCC is shown in Fig. 8. In Fig. 8, City *A* represents a typical major branch location. Users with low-speed terminal devices in the metropolitan area of City *A* would place a local (toll-free) call to the low-speed access rotary. As in the GE and TYMNET systems described previously, a variety of low-speed data terminals will be handled by this system. Upon hearing the tone from the low-speed data set at the RCC (Bell 103E5 or 113B), the user types a single character. The RCC will use this character to determine the terminal speed and code type. Currently, INFONET supports ASCII code at 110, 150, and 300 bits/s (10, 15, and 30 characters/s), and IBM Correspondence and EBCD codes at 134.2 bits/s (14.8 characters/s). All terminal devices compatible with these code descriptions may be used with the INFONET system.

Once the RCC has identified the code and terminal type, the user may sign on the system and perform his desired tasks. RCC software converts all terminal codes to ASCII; This relieves the central computer of performing any code translation tasks.

In addition to providing access for low-speed terminals, the RCC accommodates high-speed (2000 bits/s), remote job entry (RJE) dual access (2000 bits/s), high-speed RJE with dedicated lines (up to 4800 bits/s), and multiplexer ports. Currently, the network supports all remote terminals (card-reader, card-punch, and line-printer) which are compatible with the 2780 Binary Synchronous Communication discipline.

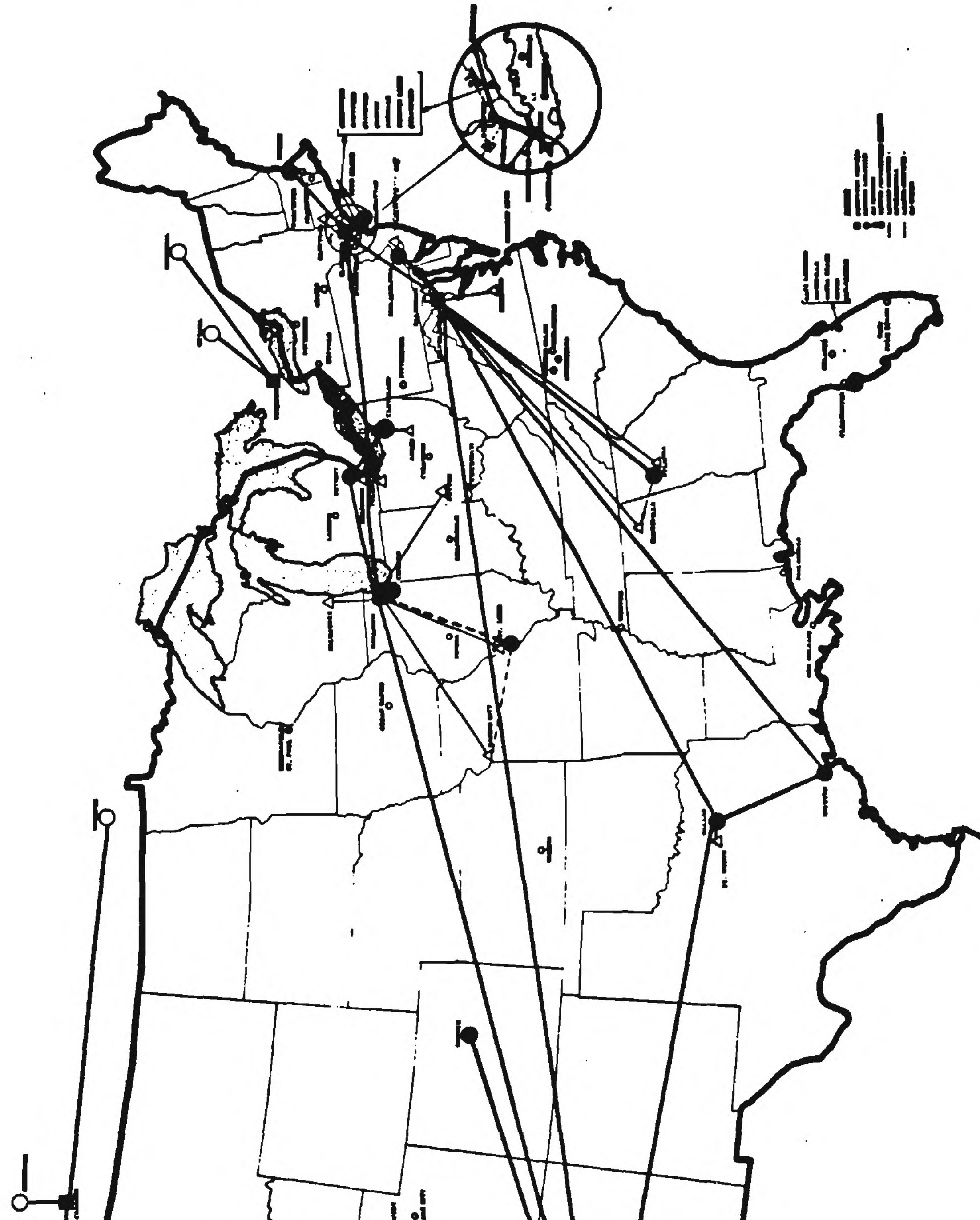

Fig. 7. INFONET communications networks.

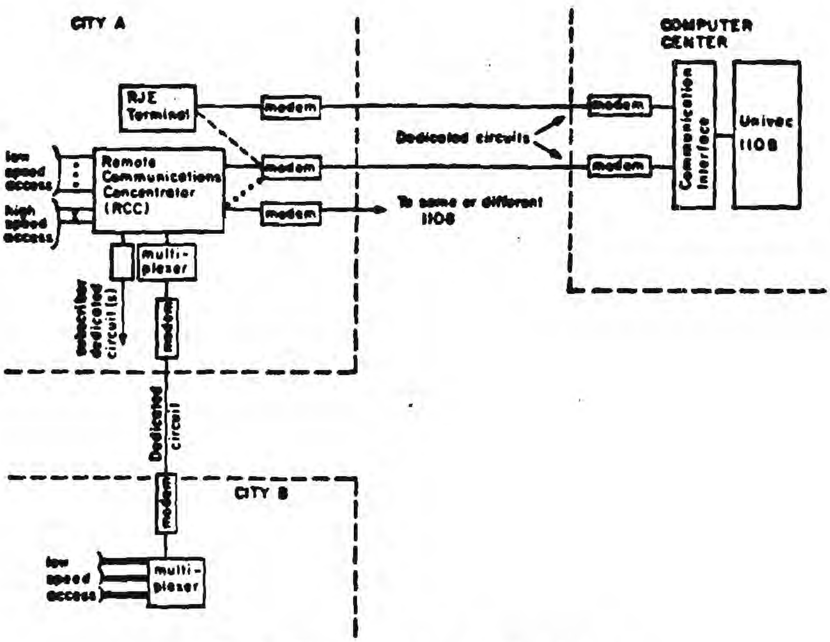

Fig. 8. Functional schematic of INFONET.

ɪr disciplines may be accommodated by adding a new -speed terminal handler (software) in the RCC.

ligh-speed dial access permits users with their own RJE inals to access INFONET via a local call and a standard System 201A data set (or equivalent). Users with a re- ement for a dedicated RJE circuit may interface the RCC standard Bell leased circuits and either Bell or non-Bell ems.

ls depicted in Fig. 8, the RCC may also be used as an face for multiplexer links. Typically, cities with smaller c requirements will be served by a multiplexer with ution to an RCC as usage demands. INFONET uses -division multiplexers in conjunction with high-speed hronous modems for these applications. The multiplexers ynchronous character-oriented devices with frame divi- such that 10-, 15-, and 30-character/s inputs are ac- nodated. Since the multiplexers do not have provision utomatic speed and code detection, separate telephone y groups are provided for each of the various terminal es served.

'he multiplexers are connected to the nearest RCC via a cated circuit and synchronous modems. Forward error ction is used on certain multiplexer links to overcome smission errors. The code is a rate-$\frac{3}{4}$ convolutional burst cting code. The transmission rate is 4800 bits/s with an mation rate of 3600 bits/s. The burst correction interval the span over which all errors are guaranteed to be cor- d) is selectable at 32, 64, 128, 256, 512, or 1024 bits; this e is dependent upon channel characteristics. The longer ction intervals introduce greater delays into the system; rection interval of 256 bits is normally used.

'he primary communication link from the RCC to the is a Bell System C2 dedicated full duplex circuit. The smission rate (modem speed) is selected according to ipated input load. Currently, transmission rates of , 7200, and 9600 bits/s are used. The software and hard- has been designed to accommodate higher rates; how- these have not been utilized to date because of adverse performance and economies of remote transmission above 9600 bits/s. RCC's which are located together with an 1108 may operate at 19 200 bits/s since there is no complex modem/transmission path to be considered.

As indicated in Fig. 8, each INFONET branch office has a high-speed RJE terminal. This terminal may communicate with the central computer either via dedicated circuits or directly interfaced with the RCC. Typically, a separate diversely routed circuit is used, with this circuit serving as a backup for the RCC. (In this case, the RJE terminal would use the dial-up backup which has been provided.) In all cases, an INFONET branch has at least two dedicated diversely routed circuits (to increase overall reliability) connecting the branch location to the central computer site.

Further flexibility is achieved by the multiple trunk capability of the RCC. As shown in Fig. 8, the RCC can serve two distinct high-speed trunks. This facilitates access to two distinct 1108's from the same RCC. For example, users in city *A* could access either the regional center or the national center depending upon their specific requirements. Similarly, the dual high-speed trunks may be connected to the same 1108 if required by capacity considerations. This same functional capability may be achieved in cities served by multiplexers. This is obviously less efficient than the RCC implementation but is used if that functional capability is required for a particular city.

This network has been designed to facilitate load balancing in a way similar to that previously described in the GE system. If one central processor becomes heavily loaded, one or more RCC's serving that processor may be shifted to another 1108. User files are transferred on an overnight basis, the communications are realigned, and the shift is accomplished unknown to the user.

The network was designed to facilitate a logical evolution of hardware in each city. The most economical means of servicing a given load is a complex function of statistics of the user population, distance from the central computer site, and other RCC's and intra- and interstate tariffs. A general

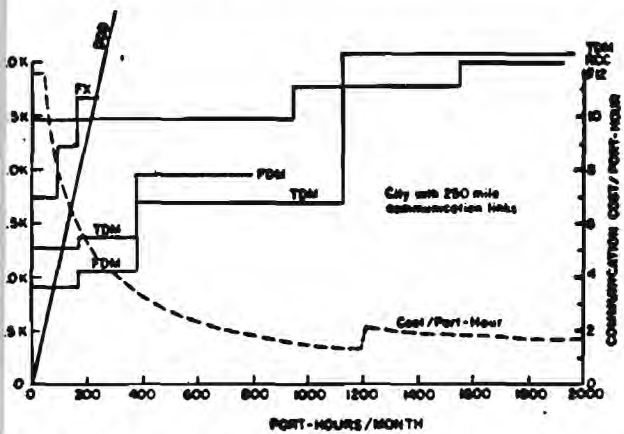

Fig. 9. Economics of data communications—Summary.

lution within a city may be from Direct Distance Dialing DD) to Foreign Exchange (FX), to time-division multi- xing (TDM) and/or frequency-division multiplexing DM), and finally to an RCC. Calculations as to the eco- nics of network growth, characteristic of all the networks cribed in this paper, may be carried out on the basis of ves such as those given in Fig. 9.

Fig. 9 illustrates an example of the basic economic trade- for a city which requires 250-mi communication links. The cissa is a measure of incoming load and is expressed in t-hours per month. Loading and rotary capacities are ed upon Erlang B statistics with a daily peak-to-average io of 1.8 and a design busy probability of 0.05 during the k hour. The step functions are points at which new hard- re is assumed to be added to meet capacity requirements. ordinate shows monthly expense for this example; inter- te tariffs, hardware amortization, and local data service are luded.

The dashed line in Fig. 9 is referenced to the right-hand inate. This line shows the locus of minima and is normal- l to cost per port hour. This curve shows the high "startup" t for providing service in a new location. Similar relation- ps may be obtained for different distances; the relation- ps become more complex as adjacent RCC's and multi- nt networks are considered. Hence the above should be wed as illustrative of the considerations involved but not strued as a "design chart."

As is true of other networks, operational reliability is of amount importance in the network operation. Incor- ated as an integral part of the network design were such ects as extensive fault isolation, on-line performance nitoring, instrumentation, and redundancy. On-line per- mance monitoring includes both hardware and software ans. The objective is to sense circuit degradation before it omes sufficiently adverse and affects user terminal per- mance. Communication hardware used in the network tains complete loopback facilities to facilitate fault isola- . For example, high-speed modems have both analog and ital transmit and receive loopback.

note Communications Concentrator (RCC)

The RCC was built for INFONET by Comten Corp. and esignated the Comten-20. The Comten-20 has a maximum e memory size of 65K bytes, which may be incrementally reased in 16K-byte modules. Typical INFONET configura- ns use 48K words with variations determined by such factors as total load and conversational bulk-terminal mix. Cycle time of the Comten-20 is 900 ns.

The Comten-20 communication interfaces are designated Modem Interface Modules. A combination of asynchronous and synchronous modules are used to interface with the range of terminals and speeds supported by INFONET. The mod- ules provide the necessary timing, data-set interfacing, auto- matic answering, and error checking (either cyclic redundancy check or longitudinal/vertical parity checking) required to interface the communications network with the RCC software.

One of the more important and interesting functional characteristics of the software is the combined ability to allocate buffers dynamically and provide a temporary choke mechanism. This choke mechanism permits operation at high trunk utilizations without the inherent risk of buffer overflow which is characteristic of statistical multiplexing. As a func- tion of buffer filling and trunk utilization, the RCC will auto- matically slow down the terminals by appropriate action. As either input or output to the RCC approaches capacity, RCC buffers will "choke down" and reduce terminal trans- mission rate. For example, the apparent print rate of an RJE terminal may be temporarily slowed down by a small per- centage in order that conversational terminals may not be affected.

As evidenced by the description of the network, the RCC is the key element of the INFONET communication system; there are currently about 25 RCC's in the network. They are the major "building blocks" which provide both the flexibility and the capacity for network expansion.

A major aspect of the flexibility of the RCC arises from its ability to interface with low-speed, high-speed, and multi- plexer inputs. For example, in Fig. 8, routing the lower traffic density of city B via the RCC in city A is substantially more economical than routing that traffic directly to the computer center if city B is considerably closer to city A than to the computer center.

The statistical (asynchronous) multiplexing function of the RCC permits a much more efficient dedicated circuit utiliza- tion than synchronous TDM, which is, in itself, more efficient than FDM. The RCC realizes this efficiency by taking ad- vantage of the statistical nature of both inbound (toward the computer) and outbound (toward the terminal) data. For a representative discussion of statistics of time-sharing systems inbound and outbound traffic, the reader is referred to [11]. Experience at INFONET has shown that inbound traffic statistics are evolving from those presented in [11] to a higher utilization per input terminal; this is attributed to the increased use of higher speed asynchronous devices (e.g., 30- character/s CRT devices) and increased use of magnetic tape cassettes. The net effect is a requirement for increased buffer space in the RCC.

The RCC provides sufficient high-speed trunk buffer space to permit a complete full duplex error-control system. Data in both inbound and outbound directions are formatted in variable length blocks which may contain up to 2048 informa- tion bits. Positive and negative acknowledgments (ACK/NAK) are embedded in data blocks to reduce message-acknowledg- ment time. All blocks are verified as correct by either the 1108 communications interface (see Fig. 8) or the RCC, depending upon the direction. This positive error detection and retrans- mission facilitates the use of higher speed data transmission between RCC and 1108. That is, while bit error probabilities increase at the higher data rates (7200 and 9600 bits/s), the block throughput remains on the order of 99 percent and the ct is transparent to the user. In addition, the use of the data rates is a more efficient use of a standard voice eased circuit.

ery significant system feature made possible by the the shielding of the user from temporary communica- system problems. During such problem periods, the ll observe a "STANDBY" message but will not be "dropped e system. Upon correction of the trouble condition, the ay resume his session. (The system will even inform the last valid transmission.)

RCC is designed so that the software can be remote- from the central computer site. This capability is ant since many remote sites are INFONET sales which are not staffed on a 24-h basis. Operations per- may remote-load (bootstrap) the remote RCC and it to operation after a major communications outage, ter failure, or normal shutdown. Similarly, RCC soft- hanges may be made without visiting the RCC physical n to perform the change. This remote loading is a l mode of operation in which the 1108 commands the o consider a block of information as an executable pro- rather than as data to be sent on to a terminal.

e capacity of the RCC, expressed in terms of number of aneous users, is a complex function of user input and t statistics; a mix of low-speed, asynchronous, and high- RJE terminals; buffer size; and high-speed trunk ca- . Typically, INFONET RCC's are configured for a num of eight RJE ports and 64 low-speed ports. High- trunks range from 4800–9600 bit/s. The precise con- tion for any specific location depends upon the customer nd projected growth.

he RCC capacity is essntially limited only by the high- trunk capacity and not by any number of physical input . Because of this, it is difficult to discuss the number of inals" supported by a single RCC. Experience has shown the 48 low-speed/4 high-speed configuration results in an nd. and outbound statistical distribution of the com- e information rate which is at or below the trunk maxi- data rates and thereby provides the design performance. ince the state of the art of statistical or asynchronous iplexing is quite new, the RCC was heavily instrumented aintain continually good performance. The work of Chu was used as a guide during the design. However, the iple tandem buffers used in the RCC software lead to lved problems of queuing theory. Hence the approach to parameterize the design so that optimization could r as buffer interaction became known, based upon ob- ed behavior. The RCC collects statistics on buffer usage error rates and reports these statistics to the 1108 for equent analysis.

Diagnostics have been provided in the RCC to assist in lem analysis. There is a remote dump program which the ral computer can load into the RCC, in case of a software r; the content of the core is then communicated back to central computer. It is also possible to diagnose certain C hardware faults by a remote diagnostic program. The C was designed so that it can be used either remotely or escribed above or located together with the 1108; location ansparent to the operating system. Because of this design ept, it was not necessary to provide a local "front-end" puter for the 1108—the RCC provides all required func- s; hence a user's transmission is always routed via only RCC. This concept provides fewer queues than there would be if the concentrators were concatenated, and therefore tends to provide shorter response times.

Conclusions

This paper has presented descriptions of four representative terminal-oriented computer-communication networks. All four have been operational for some time now and are continually in a state of growth and modification. The GE and TYMNET systems evolved from remote conversational-mode computing systems; INFONET was designed from the beginning to handle remote job entry and batch processing along with conversational general computing, while NASDAQ had the narrower objective of remote automatic quotation and updating of files. Nevertheless, the communication-network features of all four show a great similarity in structure and function. A key component in all the networks is a programmable concentrator which not only permits more economical use of the communication lines, but affords the opportunity to do the vital communication tasks such as buffering, line control, message assembly and formatting, error control, and traffic control. The concentrators, whether remote or located at the central computer site, handle virtually all the communications functions of the network, leaving both the user and the computer free to perform their primary tasks. In addition, since the concentrators (which are essentially minicomputers) are programmable, they can be modified to accommodate any new needs that arise in the network. All of the networks contain considerable sophisticated software for network control, which was only lightly touched upon in the paper.

The evolution of computer-communication networks such as those described in this paper and others is progressing at a very rapid rate, and the pressure is constant to expand the network and add new features. For example, because of the adaptability of software as contrasted with hardware, there will likely be a tendency to replace hardware devices with programmable ones. The trend has been established, and the movement toward more "intelligent" terminals and concentrators will be inexorable.

There is already pressure to introduce network features such as higher speed dialup, positive error control complete from terminal to computer, higher speed asynchronous terminals (120 characters/s), and even provisions for computer-to-computer communications with all the potential for file and load sharing. Virtually all the existing networks today rely on leased lines from the common carriers such as AT&T. The evolution of the special service carriers such as DATRAN and MCI may have a significant impact not only on the growth of the networks, but on the design philosophy. This would be especially true if the tariffs were based on the number of bits transferred rather than monthly cost of a voice grade line. The economic factors (principally communications costs) play a dominant role in the design of these networks. Finally, the introduction of domestic communication satellites within the next five years is certain to play a part in shaping data networks.

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Computer Networking Technology – A State of the Art Review *

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Introduction

The importance of computer networking as a powerful national force is now being recognized both in the public and private sectors[1]. The necessary computer and communications technologies are rapidly evolving and, while a large number of networks are fully operational, there is extensive continuing research and development underway that promises greater efficiencies and capabilities than those realized on a wide scale today.

In this paper the highlights of computer networking technology as represented in existing and planned networks are reviewed. The authors employ as inputs the technical literature and their personal experiences and those of their colleagues in planning and using networks and in evaluating the fast-moving developments in the field. For the purpose of this review, a computer network is considered to be any interconnection of an assembly of computer systems and/or terminals together with communications facilities. Terminals range from simple data capture devices to teletypewriters to keyboard/displays to remote job entry (RJE) terminals, and may themselves include mini or larger computers.

Selected networks have already been surveyed in the current literature,[2,3,4] so rather than again survey networks themselves, this paper first identifies and discusses the components of state-of-the-art networks, then reviews how they are configured and controlled, and concludes by summarizing several major challenges that now face network planners and designers. The capabilities and limitations of several networks are referenced, as appropriate, but no attempt has been made to be comprehensive either in coverage of every network or type of network or of all network characteristics.

Network Components

All computer networks may be viewed as composed of a set of nodes and circuits or channels as shown in Figure 1. Depending on the network, the nodes may vary from a very small amount of fixed hardware logic to a large scale computer system. Some of the nodes are used only to support the network's connectivity, perhaps as concentrators or message store-and-forward computers. Other nodes (sometimes also serving the above function) are the external attachment points for terminals and computer systems.

As will be discussed later, in some cases a network access node and its attached computer may physically be the same component. It may be desirable for some networks to consider the "network proper" to extend through the circuit that connects to the external equipment, or even to extend the concept to include the special network access software within a connected computer system. An example of terminology as used for the experimental ARPA Network (Department of Defense Advanced Research Projects Agency)[5] is to consider all of the nodes and the computer systems, but not generally the attached terminals, as part of the resource sharing computer network, and to consider the part encircled in Figure 1 as the "communications subnet."

The only kind of network configuration that may not be cleanly described by the model of Figure 1 is that in which a number of terminals or computers are connected to the same circuit on a series or parallel basis. For this configuration, one can envision a series of nodes on a "ring" type circuit[6] in which each node's successful operation relative to maintaining circuit continuity and network access may be dependent on the proper operation of the attached terminal or computer system.

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As a basis for discussing network architecture and other ies, it is useful at this point to briefly describe the types nodes and circuits or channels from which these nputer-communications networks are constructed.

cuits or Channels

The term "circuit" is usually used to refer to a nt-to-point physical or seemingly physical path which support continuous communication in one or both ections. For data transmission purposes, the actual nsmission may employ either analog or digital tech- ues, and, if analog, require a modem (modulator- nodulator) at each end of the circuit. Modems are cribed in some detail in a recent review[7] and circuits and ated present and planned common carrier offerings have been summarized[8,9,10].

Circuits are supported using a variety of media, such as ysical copper wire; microwave links (usually multiplexed as to support many smaller capacity circuits); hf, vhf, l uhf radio links; satellite radio links; and two-way cable installations. For the purpose of examining computer tworks, it is normally not necessary to be concerned out the media or the transmission method, and it is equate to consider as the basic element a "channel," corporating a physical transmission medium, modems if cessary, and other equipment. The important parameters the channel are its maximum data rate, its error aracteristics, its delay characteristics, and its directional itations, if any. It is also useful to consider circuit setup aracteristics if a point to point circuit is not always dicated to a network. These setup characteristics may clude the signalling mechanism and delay, circuit setup lay, and the delay for breaking the circuit.

Available channels begin at the low end with those that ovide a 60 to 100 bps (bits per second) data rate, fficient to support a slow speed teletypewriter terminal. "voice grade" channel, suitably conditioned, now sup- rts 2000-9600 bps. Error rates experienced at these data tes are on the order of one in 10^5, but more meaningful ock-oriented error rates vary considerably depending on w the channel is used and controlled[11,12]. Higher ndwidth channels can be supplied, such as the 50 Kbps annels employed in the ARPA Network. A voice capacity annel is now in operation through the Pacific Intelsat IV tellite supporting 50 Kbps for a link of the ARPA etwork. If needed, much greater channel capacity can be ade available using conventional telephone plant or new aveguide or laser technologies.

The allocation of channels for data transmission is erformed in several different ways. If a large amount of affic is expected from one point to another, the entire hannel may be dedicated indefinitely to that transmission. therwise, most networks provide a mechanism for effi- ient sharing of each channel. This is especially important or data communications, since few data transmission equirements exactly match the capacity of available hannels, and the nature of data transmission is typically urst-oriented, where the communicating computers or erminals have need for a specific data rate for a short time eriod and then have no need for transmission for a more xtended time period.

Frequency division (FDM) and synchronous time divi- ion (STDM) multiplexing, in which a channel is divided nto a fixed number of fixed capacity subchannels, have een well described in introductory material[13]. These echniques assist in overcoming the channel capacity matching problem and permit dividing of a high data rate channel into a number of lesser ones, but there is no efficiency gain through taking advantage of the burst characteristics of data communication. Asynchronous time division multiplexing (ATDM) can be used to switch the channel from one subchannel to another on an as needed basis[14]. Although making better use of the channel, the equipment needed at the nodes to which the channel is attached requires decision logic and buffer space. Another type of ATDM is the allocation of a ring type circuit, in which, for example, the nodes gain access to the channel by picking an empty "slot" as the data stream flies by around the ring. In this way, slots are employed only as needed and even then not necessarily used around the entire ring[6,15,16].

Variants of the above types of multiplexing, in which the sharing of the channel is on a frequency bandwidth basis for FDM or on a bit or fixed length byte basis for TDM, involve the allocation of the channel for longer, possibly variable periods to each subchannel. In message switching, an entire message or a major portion of it may be transmitted as a unit through one or more store-and- forward nodes, and possibly even stored for later delivery. In packet switching, the size of the message segments, or packets, transmitted at one time is tightly restricted and every effort is made to combine efficiency of channel use with a guarantee of access over a short time period to each subchannel or its equivalent in a particular network's terminology.

Random access techniques can be employed to allow nodes to compete for a channel rather than have a more rigid allocation mechanism. In the ALOHA System a single radio channel is used in this manner[17], and the "media is the multiplexer" as several nodes compete for the radio channel. Various approaches to resolving channel access conflicts have been demonstrated or proposed, and current efforts are directed to "slotting" such a channel to minimize the probability of conflict. Related concepts now receiving attention are a reservation system that allocates a portion of a channel's capacity for continuous types of transmission and the application of these burst random access techniques to satellite-based radio channels[18].

Nodes

A network node, as the term has been used here, performs a number of network internal functions and can be the network interface to the outside world. A node controls outgoing traffic on some or all of the channels connected to it through a channel allocation mechanism. If the node is simply a multiplexer, this function is performed by hardware that multiplexes the outgoing channels in either the frequency or time domain[19].

If the node is a "concentrator," having as inputs a variety of character asynchronous or synchronous com- munications channels, then a stored program computer with a reasonable amount of buffer space is necessary to efficiently package the outgoing data. A concentrator typically combines inputs from a number of slower speed channels for transmission on a higher capacity outgoing channel in addition to performing the opposite data distribution function to the slower speed channels.

Where there is more than one output channel, the node must perform a "routing" function of both determining the appropriate output channel and packaging the data in units for efficient use of each outgoing channel. The method for determining the appropriate output channel is a primary characteristic of the control mechanism for a network.

The types of functions just described are most appli-
ible to message-switched communications, in which a unit ' data which may be referred to as a "message" is stored id then forwarded through each node. In many networks, iis store-and-forward action occurs quickly, with storage ily while an output channel is being chosen and until it comes available[20,21,22]. In the ARPA Network, for stance, the design end-to-end network delay through veral store-and-forward nodes is less than 0.5 second[5].

In some networks a node performs circuit or direct iannel switching, directly connecting channels or derived ibchannels to other channels terminating at that node. ontrol of this switching may be by a minicomputer at that ode[10]. A dissertation on the sometimes subtle differences :tween circuit and message switching is beyond the scope this paper, but an interesting discussion is contained in a aper by Kahn[23].

Additional nodal functions include those for ensuring ie integrity of the data that passes through the node. One rm of this assurance is through channel error control icorporated in what may be termed "line control proce- ures"[24]. Hardware and software for testing node/channel iterfaces can be included along with that for loop testing f attached bidirectional channels. A node may also contain gic for measuring the flow of network traffic that passes irough it. This logic can be useful both for allocating etwork costs and for determining the performance of etwork components with a long-term objective of improv- ig the network. In a sophisticated network of the ARPA ype, the node actually contains the necessary logic for ootstrapping new versions of its operating software into it hrough one or more of the attached channels[25,26].

Finally, referring again to Figure 1, some of the nodes ermit network access, and thus must contain interface ardware and software for computer systems, terminals, or oth. This is a very important topic, and an entire portion f the Network Architecture section of this paper is evoted to this interface function. It should be noted that he nodes at the periphery of the communications subnet nay be incorporated in attached service computers or other acilities. In at least one network, TSS, such attached ervice computers are an integral part of the communica- ions network[27].

The present economies associated with minicomputers ave led to their use as nodes that perform many of the ibove functions. In the interest of reliability, multi- processor minicomputer configurations have been proposed and are being designed[28]. Especially in networks having large numbers of nodes, there is an economic force limiting the number and kind of functions performed within the node. This kind of force can lead to buffering constraints and processor limitations before attached channel capacity has been saturated.

Network Architecture

The basic attributes of a network that distinguish its architecture include its topology or overall organization, composition, size, channel type and utilization strategy, and control mechanism.

Topology

Alternative network topologies include (1) highly cen-

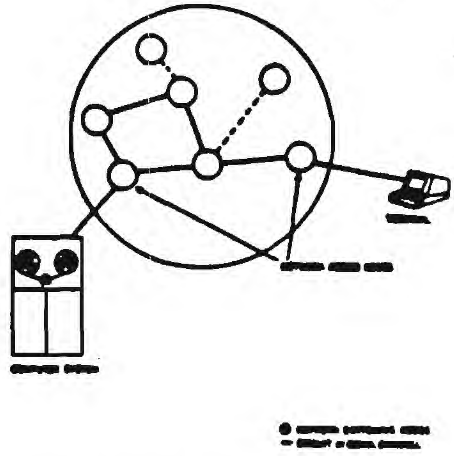
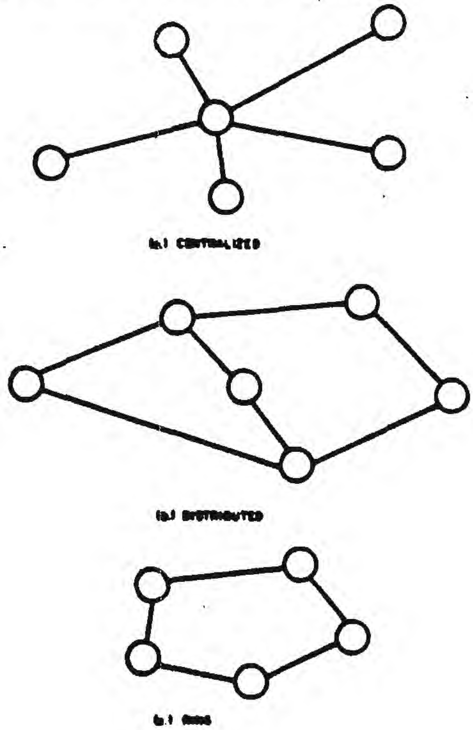


Figure 1. Computer Network Model

tralized or star; (2) fully distributed, either partially or fully connected; (3) ring, which is a variant of a distributed configuration; or (4) various combinations of these. Figure 2 illustrates some of these possibilities.

A simple time-sharing system, with channels radiating from a central computer system, and perhaps, multiplexers or concentrators serving to fan in still other radial com- munication channels, is an example of a centralized configuration. This organization can be applied on a local, national, or even international scale. However, when it is desired to have serving computer systems themselves

Figure 2. Alternative Network Configurations



graphically separated, yet perhaps serving a number of nmon terminals, a set of superimposed star configura- ns can lead to the sharing of communications facilities ere there is substantial geographical overlap. These iditions, plus a requirement for general computer-to- nputer communications, can result in a more distributed work. The ARPA Network is distributed, but not fully nnected. Such full connection would be very expensive. reasons of reliability, it is, however, two-connected; t is, between any two nodes there are at least two tinct paths.

The MERIT Network[22] is distributed, but fully con- ted. Its three nodes, each of which has a computer tem attached, can obtain a dial-up communication nnel to each of the other nodes. A ring network, such as t of the Distributed Computer System (DCS),[15,29] is a m of distributed network designed for local networking h possible national extension and utilizing a T1 compati- 8 communication system. A bidirectional national ring is ng built by the National Weather Service and will tain dedicated voice grade circuits with backup dial-up ability[16].

The introduction of a shared satellite channel compli- es the topological picture. Although the satellite link as sently used in the ARPA Network is simply another d of communication channel, the prospects for its red use by a number of nodes connected to different th stations could bring about a different structure[18]. In e sense the satellite becomes a network node having tential channels to several connecting nodes. It could n be considered the central node in a centralized twork, through which all communications must pass.

In the above discussion, the concept of topology was roduced relative to placement of nodes as defined earlier. tual placement of computing power, control of network itching, and other functions need not be centralized or centralized according to the node distribution, although the case of a centralized time-sharing system they happen be. In the ARPA Network and DCS all of these are tributed, but in TYMNET, network control of the tributed network is centralized.

mposition

Network composition can be either heterogeneous or mogenous, depending on either the similarity of the des or of attached computers. Even if all of the mmunications nodes are essentially identical, as for the RPA Network, the network can be basically heterogene- s if the connected computer systems are of different pes or manufacture. The term "heterogeneous" has been plied, however, to networks having different models of e same computer[31].

It is clear that the complexities of interconnection rough a network are increased in a heterogeneous twork. Even for a network that serves a variety of slightly fferent terminals, substantial additional effort may be quired for successful operation. For example, the connec- n of non-ASCII terminals to the ARPA Network rminal Interface Message Processors (TIP's)[30] has led to ditional programming and the use of at least 1000 16-bit rds of main memory in each TIP.

ze

The network size generally refers to the number of des or to the number of connected computers or rminals. Of particular interest are the size limitations inherent in different approaches to networking. For instance, the ARPA Network and similar networks cannot simply be expanded to 100 or 200 nodes in the present manner without significant reworking of the routing strat- egy[32]. At present, each node must have a table entry for every other node in the network. These tables simply keep growing as the net grows. A hierarchical structure, in which packets are routed to the general region of a destination node, has been discussed as a solution to this problem. The addressing and even the general structure of the network might even tend toward that of the public switched network, in which four levels of such addressing and routing are sufficient to traverse the country. Whether this would significantly change the nature of the ARPA Network or its basic control strategy is an item for conjecture.

Channel Type and Utilization

A network may be homogenous with regard to its communications channels or it may employ a variety of channels as needed. Actual network design can frequently employ a mix with little change to the remainder of the network. For example, the ARPA Network is essentially homogenous in this regard, with 50 Kbps channels. Smaller or higher capacity channels can be used instead with little difficulty, except for a resulting change in overall network capacity. The use of 50 Kbps channels in the ARPA Network gives it the flexibility to handle a combination of highly interactive traffic together with data transfer in support of remote job entry and computer-to-computer communication. How well it can handle various mixes of interactive and non-interactive traffic using present control and routing strategies has not yet been demonstrated, but analyses have shown that success is highly probable with significantly different degrees of overhead for different traffic mixes[28].

A network such as TYMNET, initially designed to handle interactive traffic efficiently, may not be readily adaptable to serving RJE terminals and high speed computer-to-computer data transfer. The simple addition of higher capacity channels may offer little relief if the node processors are near saturation. This raises the issue, which will not be further addressed in this paper, of the necessity or even desirability of supporting all types of data communication with a single integrated network. The economies of integration have yet to be discussed, much less clearly demonstrated, in the technical literature.

The topic of channel utilization again brings up the basic question of message switching versus circuit switching. In the earlier discussion, the attention was focused on alloca- tion of individual channels. On a network-wide basis the concern is with paths or routes through the network for individual transmissions. In a circuit-switched network a physical or apparently physical path may be set up and maintained for the duration of the transmission. In a message or packet switched network, even though no physical path is set up, a logical or virtual path may actually be defined. In TYMNET, a virtual circuit is set up that establishes a fixed path through a number of nodes that connects a particular terminal with a "host" computer system. This path, which defines the routing of packets in every node along it, remains fixed until broken by the terminal user, the computer, or in case of network component failure. In the ARPA Network, the host-to-host protocol[33] defines the endpoints of a path which remain so

fined for an extended period of time. Actual routing of ch packet through the network is, however, completely ynamic and adaptive to current network conditions. alden[34] has proposed the elimination of even this vestige circuit or path definition through a more dynamically laptable host-to-host protocol.

etwork Control

Network control is usually either highly centralized or ompletely distributed. In a topologically centralized net-ork control is usually exercised from the center. In a istributed network, such as the ARPA Network or the CS, control is actually completely distributed and resides algorithms explicitly or implicitly contained within the etwork nodes. In TYMNET, although the network topol-gy and computational resources are distributed, control is entralized within a control computer which can be eplaced within seconds by another in the event of failure.

The control functions that must be exercised include the etup and breaking of connections between entities external o the network, including the signaling necessary for a ource to specify a destination for a one or two-way ommunication. The maintenance of these connections is he function of the routing strategy. Much attention has een given to the development of routing strategies for a acket switched network such that channels are efficiently tilized and high throughput can be obtained[24,25,35]. Attention has been given to the rather difficult problems ssociated with network "flow control" and to making sure that network congestion does not occur. In the ARPA Network, for example, heavy network loading or a destination that cannot accept continued input of data results in a backup all the way to the source, since minimal buffering is provided. The burden is then on the source terminal or computer to deal with the situation.

Network monitoring and maintenance can be assisted by hardware and software distributed throughout the network. Actual monitoring is usually accomplished from one or a few control centers. By intelligent use of automatic remote checkout logic, including remote sensing of component failure, degradation and failure can be detected and personnel dispatched for either node or channel repair[36].

Another control function is the coordination of measurement activity internal and external to the network. As discussed earlier, one function of a network node can be to make internal measurements for record keeping and network improvement purposes[37,38]. What is still missing is a means for measuring the performance of a network as seen by its users. One effort along these lines is underway at the National Bureau of Standards, and has led to the development of a new tool, a Network Measurement Machine, for recording the dialogue of an interactive network user[39]. By measurement of the same dialogue at multiple points in a network, the effect of network-contributed delays on actual service quality as seen by the user can be determined. In addition, information on actual communication facility loading for this type of network user across several classes of application can be obtained, and the actual performance of computer systems as viewed remotely through a computer-communications network can be determined with regard to response times and other measures.

Network control must also be concerned with network expansion. The addition of nodes and channels in an orderly fashion, taking into account node and channel delivery lead times and the effect of changes on overall network capacity can be a difficult task. Frank and Chou[35] have reported the use of a topological network modeling program that has been of considerable utility in supporting this function for the ARPA Network. Finally, the continued maintenance and improvement of node software for those networks having computer-based nodes must be planned and monitored. Means for loading this software, whether through the network, as is successfully done most of the time for the ARPA Network, or distribution of paper tapes or other media for manual loading must be coordinated.

External Network Interfaces

Referring again back to Figure 1, the network's external interfaces have been defined as those at which computer systems and a variety of terminals are connected. The interface must be different for remote job entry (RJE) and other terminals that utilize a synchronous communications protocol than for interactive teletypewriter and CRT terminals that use a less demanding character asynchronous protocol[40]. For example, the ARPA Network cannot support an RJE terminal through its TIP. A task is underway to build a front end for the TIP which will itself contain a minicomputer to provide the line control and buffering necessary to service these types of synchronous terminals. Meanwhile, the ARPA Network Terminal System (ANTS)[41] is already in use and is being improved to operate as a minihost within the ARPA Network to service RJE and interactive terminals as well as to interface host computer systems.

The terminal interface to the network and the attendant support capabilities of that interface are important. If terminals can connect to a network only through an ached host computer, then the user must know how to al with that computer as well as the one(s) he wants to [22,27]. In addition, substantial overhead can be accrued rough connection of terminals in this manner. There are, wever, networks which have separate interfaces for user rminals without the necessity of connecting through an ached computer system[21,30,41,42]. In the simplest case, user terminal interface is a hardwired multiplexer or ogrammable concentrator. A concentrator can usually ovide more functions for the user, such as automatic ed recognition and character code conversion, in addi- n to limited editing in some cases.

Connection of a computer system, that is, a "host mputer", to a network is a somewhat more complicated k. It is necessary that a reasonably high data rate be rmitted, and in some cases desirable that off the shelf rdware, perhaps even a standard channel for the compu- , be used and that software changes, especially to the erating system, be minimal. In the ARPA Network a ecial full duplex host computer interface is required and extensive Network Control Program (NCP) must be de available for each connecting computer system. cket Communications, Inc. (PCI), a company that is nning to offer a packet switched data communications vice on a commercial basis, has proposed to identify and rly allocate actual network costs, including a separate fee the optional installation and maintenance of a Network ntrol Program[43].

The use of ANTS to connect a CDC 6600 to the ARPA twork with no host computer hardware or software difications is planned. In this case, the NCP is removed m the host computer and placed in the ANTS system, ich becomes a front end to the CDC 6600. In TYMNET, way of connecting a host is through the use of a mber of slow speed terminal ports back-to-back with the minal ports of a TYMSAT[21]. This particular approach is aightforward, with no modification to the host compu- ; however, it is wasteful in the large number of ynchronous interfaces it requires.

In general, those approaches to host interfacing that quire minimal effort limit the host computer's network teraction to that supported by existing host communica- ns hardware and software. The issues associated with the st of NCP's and with alternative host connections have en addressed in a related paper by one of the authors[44].

onclusions

A number of points have been raised in this paper which licate a need for further research and development in ecific areas of computer networking. In some cases a orough design study relative to a given set of require- ents for a network would shed some light on still understood issues.

Of particular interest for future work is the design and velopment of large networks, especially of the packet- itched type, and the further refinement of routing ategies. Related to this is a better understanding of twork flow control, all the way from inside hosts to rminal characteristics, and the design of next-generation otocols that smooth the operation of heterogeneous tworks. New types of higher level protocols are neces- y, although not addressed in this paper, in which more tural crossing of inter-machine barriers can be achieved th regard to operating system control language and other rdensome incompatibilities.

Allocation of channels in large networks so that they can efficiently serve arbitrary mixes of traffic having different message lengths and delay requirements is another subject for study. This will be accompanied by the now intensive developmental work directed toward efficient use of multi-access satellite channels.

The interfacing of both terminals and host computers to networks of the type discussed here still requires considerable attention. The problem is acute for hosts, in which present schemes frequently introduce substantial overhead and demand special hardware and software which must be continually updated as the host system evolves.

Finally, the area of network measurement has only barely been touched upon. Continued development and testing of internal measurement techniques is needed along with substantial attention to measurement criteria, specific measures, and measurement tools for externally determining the performance of all types of computer networks.

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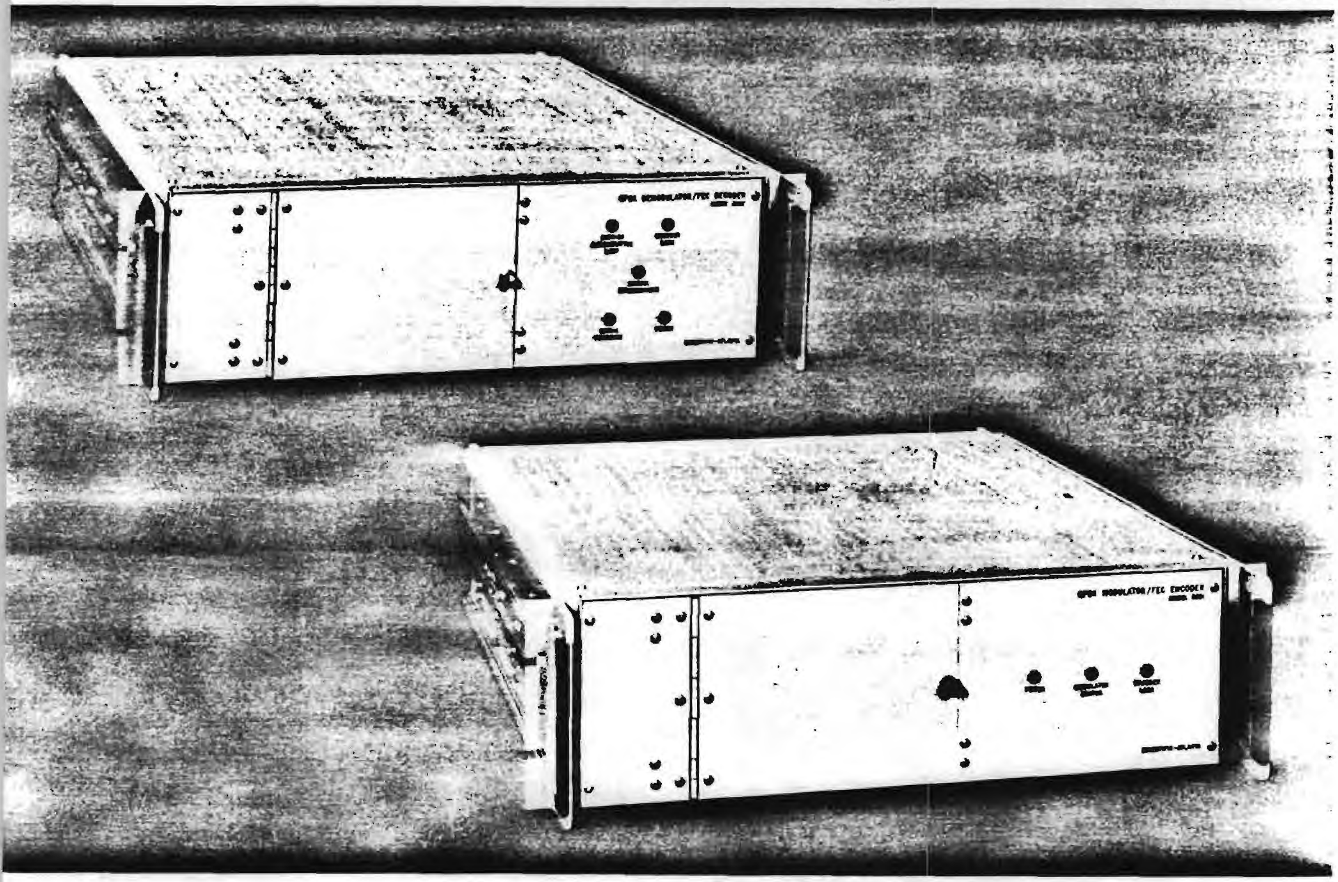
Preliminary Data
Series 8800 QPSK Modem/Codec



tures

ndwidth efficiency allows channel spacing at 0.7 x bit
e with minimal ACI.
te – 7/8 FEC coding
ta rates 30 kb/s to 10 Mb/s
C and AGC allow for ±25-kHz acquisition range and
dB level variations
ernal high-stability data clock and elastic store optional
nthesizer option available for complete frequency
lity

Description

Two desirable properties, bandwidth efficiency and power efficiency, are combined in the Scientific-Atlanta Series 8800 QPSK Modem/Codecs. Bandwidth efficiency is afforded by using QPSK modulation with Nyquist filtering, while QPSK modulation combined with forward error correction coding yields high power efficiency.

In the modulator/encoder, self-contained interface circuitry process the input data and clock. The data are then scrambled in accordance with CCITT Rec. V35 and then coded by the FEC encoder. From the encoder, the data are routed to the bandlimited QPSK modulator. The modulator output is in the 70 ±18 MHz range.

In the demodulator/decoder, the input is double-downconverted and coherently demodulated. The filter and state estimated demodulator output is then processed by the Rate – 7/8 FEC decoder and descrambled before being passed on to the receive-interface circuitry.

Any data rate from 30 Kb/s to 10 Mb/s can be supplied: 56 Kb/s, T1 etc., are standard.

Two basic configurations are available - simplex and suplex. In the simplex configuration (shown above) a transmit and a receive unit are provided. The suplex configuration houses the modem/codec in one unit.

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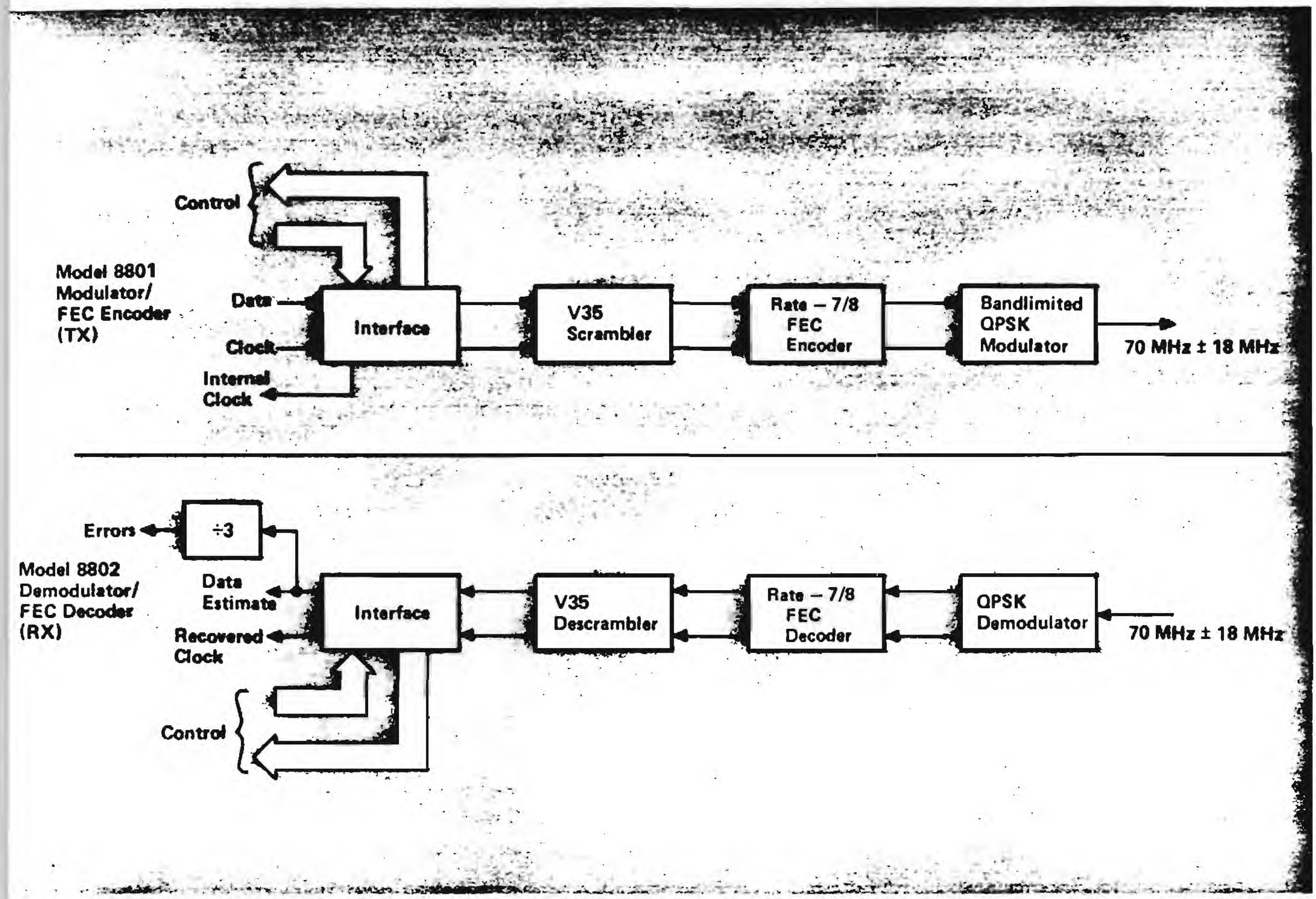
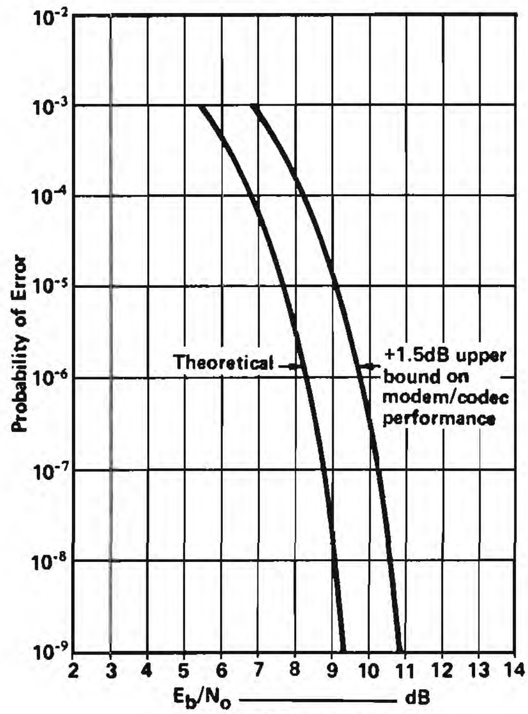


ıs shown in the block diagram, the input data and clock re processed by the appropriate interface circuitry. As an ption, an internal high-stability data clock is available for ıput to customer equipment. The data is scrambled in ccordance with CCITT recommendation V35 and then ncoded by the FEC encoder. A self-orthogonal convolu- onal code with minimum distance 7 is used. The encoded ata and $\frac{8}{7}$ R clock are inputs to the bandlimited QPSK ıodulator. The $\left(\frac{\sin x}{x}\right)^2$ data spectrum is filtered such that he overall output spectrum has a square root of Nyquist, $\overline{N(W)}$ shaping (same as impulses passed through a $\sqrt{N(W)}$ lter). A rolloff factor of approximately 50% is used ecause it provides good spectrum control, but is much less ensitive than smaller percentage rolloff filters to tempera- ure, aging, non-linearities, etc. Adjacent channels may be paced as close as 70% of the transmit data rate with ıinimal effect due to adjacent channel interference.

'he RF input to the demodulator is double-downconverted nd coherently demodulated. Both automatic frequency ontrol and automatic gain control are provided. By switch osition, the demod will receive its own modulator's ransmit frequency or its assigned receive frequency. The aseband noisy demodulated out is $\sqrt{N(W)}$ filtered and tate estimated.

'he demodulator output estimated data and recovered $\frac{8}{7}$ ıit rate clock are then processed by the Rate – 7/8 FEC lecoder. Threshold decoding with syndrome feedback is ısed to correct channel errors. A 10^{-4} input error rate, for xample, is corrected to a 10^{-9} error rate at the decoder ıutput. The decoder output is descrambled, if scrambling vas used on the transmit side, and is processed by the interface circuitry to provide the proper output levels. The ÷3 counter operating on the data output provides a means of measuring error rate if one connects the transmit input to a fixed data state. Output elastic buffering is available as an option.



Modem BER Performance

ecifications

ılator IF Interface

wer Level
-10 dBm maximum
ıpedance
75 ohms unbalanced
equency Stability
1×10^{-5}
ıtput Frequency
52- to 88-MHz center frequency
/pe Modulation
Offset QPSK
ındwidth
3 dB bandwidth equals symbol rate ~99% of signal power within 1.5 x symbol rate or 0.75 x bit rate
Allows channel spacing of 0.7 bit rate with minimal ACI
onnector
BNC

odulator IF Interface

wer Level
-50 dBm nominal,
-60 to -40 dBm
ıpedance
75 ohms unbalanced
quisition Range
±25 kHz from center frequency
put Frequency
52- to 88-MHz center frequency
/pe Modulation
Offset QPSK
t Error Performance
Within 1.5 dB of theoretical curve for modem/codec with random data (see left). Typical performance within 1 dB of theoretical
onnector
BNC

and

ata Rate
30 Kb/s to 10 Mb/s
ata Format
NRZ-L
ansmit Clock
Internal to modem, $\pm 10^{-5}$ stability OR external clock input, ±0.1% stability. Higher stability options available. Internal clock is optional
eceive Clock
Recovered from received signal
ming Jitter
Transmit ≤10% of a clock period
Receive ≤5% of a clock period
rambler
per CCITT V.35
terface
per CCITT V.35; others on request
onnector
per Bell No. 41450; others on request

FEC Codec

Code
Convolutional self-orthogonal, minimum distance 7
Rate 7/8
General Polynominal
0, 2, 8, 32, 88, 142
0, 3, 19, 52, 78, 46
0, 11, 12, 62, 85, 131
0, 21, 25, 39, 82, 126
0, 5, 20, 47, 84, 144
0, 58, 96, 106, 113, 141
0, 41, 77, 108, 117, 130
Decoder
Threshold decoding with syndrome feedback
Performance
Random errors
10^{-3} corrected to 2×10^{-6}
10^{-4} corrected to 1×10^{-9}
10^{-5} corrected to 6×10^{-13}
Duty Cycle
Continuous
Operating Temperature
0°C to 49°C (32°F to 120°F)
Power Requirements
108-132V ac, 50-60 Hz
Model 8801-( ) 65 W
Model 8802-( ) 95 W
Model 8803-( ) 160 W
Dimensions

Model 8801-( ) Modulator/Encoder	Standard EIA panel, 483 mm (19 in.) wide, 133.4 mm (5.25in.) high, 508 mm (20 in.) deep
Model 8802-( ) Demodulator/Decoder	Standard EIA panel, 483 mm (19 in.) wide, 133.4 mm (5.25 in.) high, 508 mm (20 in.) deep
Model 8803-( ) Full Duplex	Standard EIA panel, 483 mm (19 in.) wide, 178 mm (7 in.) high, 508 mm (20 in.) deep

Model-No. suffix ( ) is bit-rate designator.

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ı Jose, California 95110
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ıta Fe Springs, California 90670
: 213-949-9302

ıthwestern Regional Office
te 1131, Frito-Lay Tower
llas, Texas 75235
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dwestern Regional Office
)0 W. Main Street
lleville, Illinois 62223
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w England Regional Office
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rlington, Massachusetts 01803
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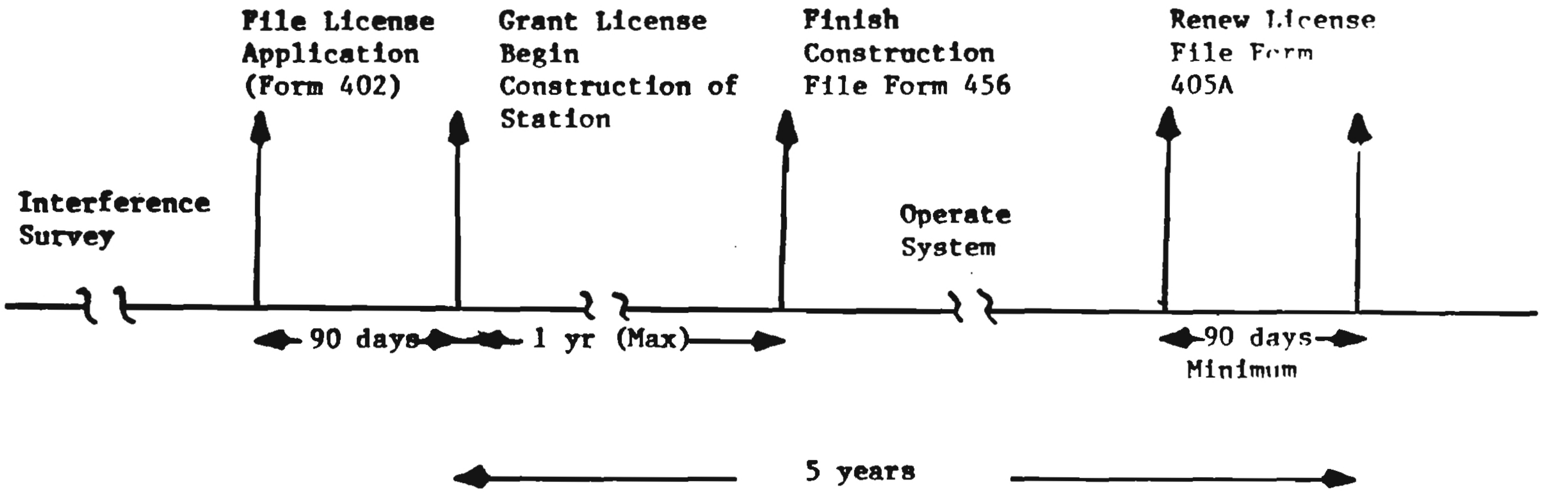


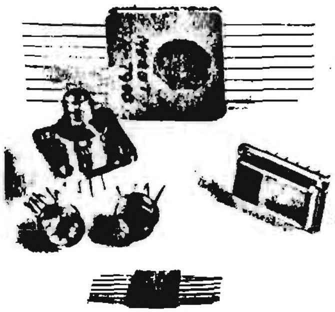
Timeline for Station Licensing

Appendix B

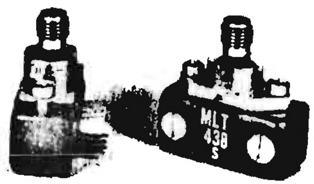
MERET

MODULES AND SYSTEMS

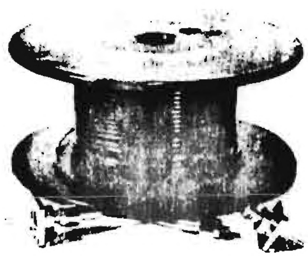
FOR OPTICAL COMMUNICATIONS



HYBRID TRANSMITTERS AND RECEIVERS



SUPERDIP TERMINALS



MODAL-SMA SYSTEMS

SHORT FORM CATALOG